VEHICLE-UTILITY POLE ACCIDENT FACTORS AND ACCIDENT RATE PREDICTIVE MODEL

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1996

To my parents

ACKNOWLEDGMENTS

I would like to extend my deep gratitude to Dr. Fazil T. Najafi, my supervisory committee chairman, for his guidance and dedicated support that made this study possible. A special thank you goes to Dr. Mang Tia and Dr. Paul Y. Thompson for their encouragement and valuable recommendations throughout my doctoral studies. Sincere appreciation goes to Dr. John Staudhammer, Dr. Bolduc, and Mr. Paul C. Kaczorowski for serving on my supervisory committee.

I also wish to thank Mr. Patrick Brady and Mr. Bruce Gorden of the Florida Department of Transportation for their personal efforts in providing valuable information for this research. I am grateful to Dr. Mark Yang in the Statistics Department at the University of Florida for his advice on statistical analysis. I am also grateful to Dr. Win G. Li for his encouragement.

Finally, I own much gratitude to my parents and family for their love, continuous encouragement and support during the entire course of my study.

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August, 1996

Chairman: Fazil T. Najafi
Major Department: Civil Engineering

Beginning with the development of the federally funded 3-R (rehabilitation, resurface and reconstruction) program, utility owners have been seeking a tool to sensibly expend capital to move poles driven by safety factors. This research provides insights into this problem.

A cost-benefit method is often used by the highway administration to prioritize projects. To perform the cost-effectiveness analysis, it is essential to get an accurate estimate of the cost and benefits of a project. In order to get a better estimation of the benefits from pole accident reduction, it is necessary to develop a good model to predict the potential pole accident frequency.

Several utility pole accident countermeasure methods have been developed since 1980. Due to technical problems and specific conditions, these methods can be used only in limited situations. Common problems include not knowing which methods are better and more effective for a given condition and specific roadway sections, the degree of improvement a corrective method can provide, and what measurable factors affect the accident rate.

In this research, the method of dimensional analysis was used to identify the structure of new model. The major parameters of the new model were travel speed, pole density, pole offset and average daily traffic volume. The travel speed was found to be one of the most important factors affecting the vehicle-utility pole accidents. It was also found that the travel speed and pole density were inseparable and should jointly affect the utility pole accidents.

A vehicle-utility pole accident predictive model was developed to forecast the rate of vehicle-utility pole accident. This model incorporates major factors affecting the utility pole accidents. In addition, a utility pole relocation project ranking system is developed for Florida Department of Transportation (FDOT).

CHAPTER 1
INTRODUCTION

Problem Statement

Vehicle crashes with utility poles cause a large number of highway fatalities and injuries every year. The Insurance Institute for Highway Safety (IIHS) estimated that crashes into utility poles caused 1,263 deaths in 1990. According to IIHS, 57 percent of the drivers killed in a roadside hazard had very high blood alcohol concentrations, and 55 percent of the deaths occurred on high-speed roads. The Florida Department of Highway Safety and Motor Vehicle reported that 6,211 pole accidents occurred on Florida roads in 1991, causing 128 fatalities, 5,733 injuries, and $32 million in vehicle damage. Police accident reports indicated that excess speed and driving under the influence of alcohol were the two main causes of pole-vehicle accidents.

A procedure needs to be developed to identify, prioritize and relocate hazardous poles both during highway construction as a consequence of road widening and as independent safety improvements. A consistent method for pole relocation has not yet been implemented in Florida. Adopting such a policy would enhance public safety and reduce tort claims against FDOT and utility companies.

The development of a reasonable and consistent pole relocation procedure is consistent with State and Federal highway safety policies. For instance, the Federal-Aid Highway Program Manual,

Section 6-6-3-2, stresses that highway agencies adopt corrective measures to deal with utility relocation, and Florida Statute 337 provides FDOT with authority to reasonably regulate utilities on public rights-of-way.

An effective pole relocation procedure should be based on accident predictive models (validated with historical data) in addition to methods for estimating the potential tort liability associated with a utility pole. The reason is that predictive models and tort liability do not necessarily depend on the same factors. Predictive models use historical accident data to forecast accident rates based on factors such as road conditions, pole characteristics, traffic volume, travel speed, and vehicle size. Tort liability depends on distinct factors such as road widening, curve clearance, prior accidents, negligent maintenance, knowledge of existing hazard, departmental policies, and community expectations as related to road safety. Most of these factors are not considered in predictive models.

The research is the logical continuation of previous studies conducted by the University of Florida and sponsored by the Florida Department of Transportation, and the Federal Highway Administration (FHWA). The first of these studies dealt with the assessment of tort liability associated with pole vehicle accidents in Florida. The other study was related to the cost-benefit evaluation of utility corrective measures.

This research identified the methods used by other states' highway agencies and investigated the procedures for prioritizing the relocation of hazardous poles developed in previous research.

The research incorporates the results of the two previous studies into one comprehensive pole relocation procedure. The project develops a procedure to identify and prioritize the relocation of hazardous utility poles. The relocation procedure is developed based on historical data, new predictive model (the UFDOT model), utility relocation and motor vehicle accident costs.

This research begins with the identification of the major factors affecting the utility pole accidents. Then, the method of dimensional analysis is used to establish the relationships between utility pole accident rates and major factors such as pole density, pole offset, travel speed, and average daily traffic volume. A new model for the prediction of vehicle-utility pole accident rates is developed. Finally, the data collected on Florida roadways are used to determine the constants of the model.

The research methodology of this dissertation can be used in other transportation research. The study provides the United States Department of Transportation (USDOT) and FDOT with a procedure to identify and prioritize the relocation of hazardous poles and a method to equitably share relocation cost with utilities. The implementation of the procedure will help reduce the number of liability claims against both the department and utilities. The DOTs and private companies can utilize more efficiently the limited resources allocated for highway safety improvement projects, and also reduce highway accidents and fatalities by eliminating hazardous poles. Appendix A shows some pictures taken from Florida Roadways.

Research Objectives and Study Scopes

The study's objectives are to identify the major factors that affect the vehicle-utility pole accidents and develop a pole relocation procedure for the FDOT. The efforts needed to achieve these objectives consist of the following tasks:

- Literature search and review
- Vehicle travel speed and pole density
- Florida vehicle-pole accident data analysis
- Identification of current predictive models
- Development of a new model for prediction of vehicle-pole accidents
- Field data collection and analysis
- Determination of the parameters of the new model
- Development of utility pole relocation procedures
- Case study

Figure 1.1 shows the organization of this dissertation.

Dissertation Organization

This dissertation consists of eight chapters. Chapter 1 provides some background of pole-vehicle accidents. Chapter 2 is a literature review that shows the state-of-the-art of the pole relocation research. It includes an extended literature search on highway facility, utility and pole-vehicle accident studies. Chapter 3 gives a comprehensive study of the relationship between vehicle speed and utility pole density. In Chapter 4, the dimensional analysis is used to verify the traditional predictive models of

vehicle-utility pole accident. A relationship between utility pole accident rate and major factors such as average utility pole density, vehicle speed, average daily traffic volume and average pole offset, is established. A general predictive model of vehicle-utility pole accident is developed using the principle of dimensional analysis. Chapter 5 determines the parameters of the new model developed in the previous chapter. This chapter details the statistical analysis for the field data and accident data. In addition, the new concept of risk factor is introduced for the measurement of driving risks in different roadway sections. A sensitivity analysis and model comparison are included in Chapter 6. Chapter 7 deals with project prioritization. Combining the research results of previous chapters, a systematic procedure of project ranking has been developed. Finally, Chapter 8 presents some conclusions and recommendations for future research.

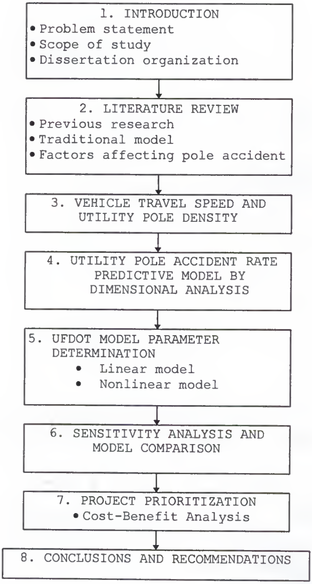

Figure 1.1: Research development flow chart.

CHAPTER 2
LITERATURE REVIEW

Previous Traffic Accident Research

A literature review has been conducted to evaluate existing models for predicting pole accident rates. There are many factors that relate to the vehicle-utility pole accident. These factors include vehicle travel speed, the location of utility pole, utility pole density or pole spacing, average daily traffic (ADT) volume, weather conditions (such as snow or rainstorm), roadway surface condition, lane width, percent of trucks in traffic stream. However, some studies found that pole offset is the most important factor that affects the vehicle-utility pole accident rate (Jones and Baum 1980). Some researchers found that utility pole density and ADT are also very important factors (Zegeer and Parker, 1983 and 1986). Some utility pole accident predictive models were established (Zegeer and Parker 1983). By studying the national and international accident experience data, Liu (1996) found that travel speed is closely related to single-vehicle accidents. Changing travel speed can dramatically change accident severity.

To improve the roadway deficiency, the following countermeasure methods were proposed (Zegeer 1986):

1. increasing the lateral offset by relocating poles farther away for the roadway

2. reducing pole density by removing a few poles

3. using breakaway poles

4. removing poles and burying utility lines underground, and

5. using protective devices such as guardrails.

The benefit of each corrective measure is calculated by first using tables and monographs to estimate the reduction in accident rate before and after the corrective measure is implemented, then translating the reduction in accident rate into a reduction in the number of accidents. The final step is computing the total benefit of the corrective measure by multiplying the reduction in the number of accidents by an average unit cost per accident or the average of fatality, injury, and property damages. These unit costs are estimated annually by the National Highway Traffic Safety Administration (NHTSA). Table 2.1 at the end of this chapter lists the vehicle accident costs. The total benefit is then compared to the corrective measure's cost. Incremental cost-benefit analysis is finally used to select the optimal countermeasure. Numerous references about the application of incremental cost-benefit analysis can be found (Zegeer and Cynecki 1986, Zegeer and Parker 1983, AASHTO 1990, Thuesen and Fabrycky, Mishan 1976, Sugden and Williams 1978, Winfrey 1969).

Traditional Models for Accident Prediction

There are many accident predictive models, but only three of them currently are considered suitable for the purpose of predicting vehicle-utility pole accident rate. These models are 1) Poisson's distribution, 2) negative binomial distribution, and 3) Zegeer's

model. Each of these models will be discussed for utility pole relocation purpose.

Poisson's Distribution

The Poisson's distribution is a theoretical formula of binomial distribution under extreme cases. This model is used for a complete random event with a very large sample size but a very small probability of the events. So this model is adequate for accident prediction. The utility pole accident rate follows this kind of distribution. But this model has its own disadvantage of variance dispersion for a larger number of events since it is assumed that the variance and events are equal. For instance, if average rate of accidents for a specific roadway section during a timed period are *p*, then its variance is also *p*. Therefore, the standard deviation equals the square root of *p*. In a form of mathematics, that is, if

$$\text{Average rate of accidents} = p$$

then its variance and standard deviation are, respectively,

$$\text{variance} = \sigma^2 = p$$

and,

$$\sigma = \sqrt{p}$$

Based on accident experience, this model can be used to estimate the accident frequency or rate with a certain probability, but it will not be able to tell how to improve the roadway deficiencies or quantitative improvement due to a project. For example, if the utility pole is moved farther away from the edge of the road, this model will not be able to tell the effect of the action or the reduction of vehicle-utility pole accidents.

Negative Binomial Distribution

The negative binomial distribution is an improvement of the (positive) binomial distribution. It can be defined in terms of the expansion of the negative binomial expression $(Q-P)^{-N}$ where $Q-P = 1$; $P > 0$. It is similar to the definition of the negative binomial distribution in terms of the (positive) binomial expression $(q + p)^n$, where $q + p = 1$; $p > 0$; $q > 0$ and n is a positive integer. Other names for the negative binomial distribution are "binomial waiting-time distribution" and the "Polya distribution." This model can be used in case of the accident variance and mean are not equal. Applications of this model can be found in some references such as Mark Poch and Fred Mannering (1996), Shankar, Mannering, and Barfield (1995).

Utility Pole Accident Countermeasure Evaluation Program (UPACE)

The last model is the Utility Pole Accident Countermeasure Evaluation program which was developed by C.V. Zegeer and M.J. Cynecki (1986), C.V. Zegeer and M.R. Parker (1983). The review evaluated a vehicle-utility pole accident rate predictive model that was developed by Zegeer et al., in 1983. The model's structure, parameters, limitations, and applicability to Florida are also evaluated. Since the ADTs on many roadways in Florida exceed 60,000 which is the upper limits of Zegeer's model, a new model is needed to be developed and adopted in cost effective analysis procedure. Therefore, to have a suitable model to predict the utility pole accident is a critical step to successfully develop a procedure for the FDOT roadway section prioritization.

The UPACE are generally used to evaluate the effectiveness of countermeasures to pole accidents without considering travel speed effect. How travel speed affects the pole accident rate remains to be seen.

Other Accident Predictive Models

For the cross section design, Zegeer et al. (1995) studied 4,951 miles of two-lane roads and found that the first foot of lane widening (2 feet of pavement widening) corresponds to a 12 percent reduction in related (AO--single vehicle plus opposite direction head-on, opposite direction sideswipe, and same direction sideswipe) accidents; 2 feet of widening (widening lanes from 9 to 11 feet, for example) results in a 23 percent reduction; 3 feet results in a 32 percent reduction; and 4 feet of widening results in 40 percent reduction. These reductions apply only for lane widths between 8 and 12 feet. The effect of shoulder widening on related (AO) accidents was determined for paved and unpaved shoulders. For shoulder width between 0 and 12 feet, the percent reduction in related accidents due to adding paved shoulders is 16 percent for 2 feet of widening (each side of the road), 29 percent for 4 feet of widening, and 40 percent for 6 feet of widening. Adding unpaved shoulders would result in 13 percent, 25 percent, and 35 percent reductions in related accidents for 2, 4, and 6 feet of widening, respectively. Thus, paved shoulders are slightly more effective than unpaved shoulders in reducing accidents. The predictive model for (AO) accidents is

$$AO = 0.0019(ADT)^{.8824}\,(0.8786)^{W}\,(0.9192)^{PA}\,(0.9316)^{UP} \times (1.2365)^{H}\,(0.8822)^{TER1}\,(1.3221)^{TER2}$$

Where:

ADT = Annual average daily traffic volume;

W = Lane width in feet;

PA = Paved shoulder;

UP = Unpaved shoulder;

H = A roadside hazard rating;

TER1 = 1 if flat, 0 otherwise;

TER2 = 1 if mountainous, 0 otherwise.

This model can be used only for two-lane, rural roadways with lane widths of 8 to 12 feet, shoulder widths of 0 to 12 feet (paved or unpaved), and traffic volumes of 100 to 10,000.

Hadi (1995) studied the Florida traffic accident data. Using negative binomial regression, he developed an accident predictive model that included the length of section, annual average daily traffic volume, lane width, number of intersections per mile, total shoulder width, speed, paved and unpaved. It is as follows:

$$AA = \mathrm{Exp}(-9.053 + 0.7212 \log(L) + 0.8869 \log(AADT) - 0.0435(LW) - 0.0262(SP) + 0.1145(IS) - 0.0123(TS))$$

Where:

AA = Total number of accidents including fatality, injury and property damage only (PDO), accident/mile/year;

L = The length of highway segment;

AADT = Annual average daily traffic volume;

LW = Lane width in feet;

SP = Posted speed limits (MPH) for the highway segment;

IS = Number of intersections per mile;

TS = Total shoulder width (PS+UP) in feet;

PS = Width of Paved shoulder (feet);

UP = Width of unpaved shoulder (feet).

This model is limited to two-lane type of roadways and lane width ranges from 9 to 12 feet.

Florida Clear Zone Policy

Historically, numerous poles were located on Florida right-of-ways according to the FDOT clear zone policy. For the countermeasure purpose, therefore, it is necessary to review this policy. The Florida "Utility Accommodation Guide" (FDOT 1990) provides design criteria for the clear zone and the location of utility poles for five types of rural and urban roads. According to this guide, utility poles are not permitted in the median. Preferably, they should be located outside the clear zone, as close as practical to the right-of way line of freeway, and at least four feet from the face of curb for urban arterial and collector roads. However, on projects where the minimum offset of four feet cannot be reasonably obtained, the minimum distance may be reduced to 2.5 feet. In locations with limited right-of-way, these guidelines allow for special cases and call for "reasonable judgments." The clear zone policy for all roadway types is summarized in Appendix B. The FDOT policy for freeways prohibits without exception longitudinal or median placement of new poles, as well as all bridge attachments. The department's utility exception policy, highway classification, and the guideline for utility accommodation for freeways and arterial roads are included in Appendix C.

Method of Cost Benefit Analysis

Cost-Benefit Methods Review

The review of methods for cost-benefit analysis results in seven basic mathematical procedures. These procedures can be used in the analysis of proposed investments for both economic evaluation and project formulation. Because each method can be applied to different types of projects, the characteristics and limitations of each of these methods are discussed. Generally, when they are properly applied in accordance with their limitations, each method will give a reliable result for economic evaluation and for project selection.

For the utility pole priority project these methods will each be compared with others according to their limitations. A suitable one will be chosen for the purpose of benefit-cost effectiveness analysis. Various uses of these procedures can be found in many references of economic analysis (Winfrey 1969, Thuesen and Fabrycky 1989, Mishan 1976, Robert Sugden and Alan Williams 1978). The brief introduction of each method is now given.

1. Equivalent Uniform Annual Cost Method.

The Equivalent Uniform Annual Cost (EUAC) Method combines all investment costs and all annual expenses into one single annual sum. This sum is equivalent to all disbursements during the analysis period if spread uniformly over the period. When more than one alternative is being examined, the one with the lowest equivalent uniform annual cost is the more economical. The present worth of

this equivalent uniform annual cost will give the same answer as obtained by the present worth of costs method.

Because this method does not consider the income or dollar value saved (or benefits of various projects), it cannot be used for benefit cost evaluation of the utility pole priority.

2. Present Worth of Costs Method

The Present Worth of Costs (PWOC) Method combines all investment costs and all annual expenses into a single present-worth sum, which represents the sum necessary at time zero to finance the total disbursements over the analysis period. This present sum, when multiplied by the capital recovery factor, will result in the equivalent uniform annual cost obtained by the equivalent uniform annual cost method. Of the alternatives compared, the one with the lowest present worth is the more economical.

This method has the same characteristics as EUAC method. It does not consider the income or dollar value saved (or benefits of various projects). Therefore, it is not suitable for prioritizing the utility pole relocation.

3. Equivalent Uniform Annual Net Return Method

The Equivalent Uniform Annual Net Return (EUANR) Method is the equivalent uniform annual cost plus the inclusion of an income factor or benefit factor. The answer indicates the amount by which the equivalent uniform annual income exceeds (or is less than) the equivalent uniform annual cost. The uniform annual costs are negatives and the incomes or benefits are positives. The alternative of having the greatest equivalent uniform annual net return is the one of greatest economy.

This method can be used to prioritize the utility project because it concerns the income factor and investment cost. It is suitable to perform cost benefit analysis for all the alternatives if more than one corrective measurement is possible for the pole relocation countermeasure.

4. Net Present Value Method

The Net Present Value (NPV) Method gives the algebraic difference in the present worth of both outward cash flow of investment and inward cash flow of incomes or benefits. It is the same in principle as the present worth of cost method, but includes the factor of annual income. The alternative of having the greater net present value is the one with greatest economy. Although this method is the same in principle as the present worth of cost method, it considers the factor of annual income or benefits of the project. It is qualified for the prioritization of utility pole relocation.

5. Rate of Return Method

The Rate of Return (ROR) Method has many different names such as internal rate of return, discount cash flow, yield rate, premium rate, and marginal rate of return. It determines the vestcharge rate, or discount rate, which will equalize the negative costs and the positive returns or benefits. As the Benefit/Cost Ratio Method, the Rate of Return Method in highway proposals usually compares two alternatives in order to develop a differential benefit. The higher the rate of return the greater the benefit.

6. Rate of Payback Method

The Rate of Payback (ROP) Method is the same in principle as that of Rate of Return Method. It equals the investment cost to the

incomes or benefits. For a given interest rate, the time period, which indicates the critical point or balanced time, will be calculated. The alternatives with the shortest payback time will be the greatest economy.

7. Benefit/Cost Ratio Method

The Benefit/Cost Ratio (BCR) Method expresses the ratio of equivalent uniform annual benefit (or its present worth) to the equivalent uniform annual cost (or its present worth). Any alternative that has a benefit/cost ratio above 1.0 is economically feasible and the alternative that has the highest incremental benefit/cost ratio is indicated as the preference. This method has been used extensively in highway works in pairs of alternatives in order to develop a differential benefit.

The Benefit-Cost Ratio Method must be applied with some other method, such as Net Present Value or Equivalent Uniform Annual Net Rate (EUANR). For most of the utility pole projects, the Increment Benefit-Cost Method--a development of the Benefit/Cost Ratio (BCR) Method, are used.

The Increment Benefit-Cost Method is a development of this method. The principle of Increment Benefit-Cost Method will be illustrated in Chapter 6.

Basic Characteristics of the Methods of Analysis

The six methods, except ROP, of economic analysis described above have common objectives. They compare the future streams of costs and benefits in such a way that for a specific period of time the analysis will disclose the probable net return on the proposed

investment or the most economical design required to produce the returns. The indicated return is in the form of dollar net profits, dollar values of benefits, dollar values of satisfaction, or dollar worth of other desired consequences. Each method applies the principles and concepts of compound interest in such a way as to take in the calculation of the differences in the worth of money over time. Each method also uses as input data the future negative and positive cash flows of money which are required to produce the returns and those that are a consequence of the investment in the property concerned. The Rate of Payback Method of the economic analysis compares the time periods of several projects by setting future negative cash flows equal to positive cash flows and to find the project with the least time. Here time is a variable.

Establish Project Priorities

After appropriate countermeasures have been selected to correct roadway deficiencies, a priority process is needed in order to use the improvement funds in the best possible way. The available funds for improvements are an important consideration, since adequate funds are usually not available to construct all candidate sections.

There are many ways to list projects according to priority. The simplest method of ranking countermeasures in order of priority is called "project ranking," which considers the economic analysis (i.e., C/E ratio, B/C ratio). After project ranking, the safety project on top of the list can then be completed first, followed by less cost-effective projects, until the available budget limit is reached. This ranking method provides a measure of which project

returns the greatest amount of benefit for each dollar invested. It does not provide a direct comparison between each project or countermeasure. If the analysis is being performed to determine which one of a number of alternative countermeasures is the best investment choice, then an incremental benefit-to-cost (IBC) should be performed. The five steps used in the incremental benefit-to-cost ratio method are as follows:

1. Determine the benefits, costs, and the benefit-to-cost ratio for each improvement.
2. List the improvements with a B/C ratio in order of increasing cost.
3. Calculate the IBC ratio of the second lowest cost improvement compared to the first. This is done by taking the difference in benefits between the second lowest cost improvement and the first and dividing the difference in costs between the two.
4. Continue, in order of increasing costs, to calculate the IBC ratio for each improvement compared to the next lower cost improvement.
5. Stop when the IBC ratio is less than 1.0

Whenever the IBC ratio exceeds 1.0, then the higher cost improvement provides a greater return for each dollar invested than the alternative with which it is being compared. Thus, an increase in expenditure is justified as long as the resulting additional benefits exceed the resulting cost increase (Sugden and Williams 1978, Winfrey 1969).

Summary of the Literature Review

The number of available references relating to vehicle-utility accidents, as a whole, is limited. Only a few studies provide a comprehensive approach toward pole accidents. Most of the research was conducted in the early 1980s. The only model that can be used for the utility pole accident prediction was developed by Zegeer et al. (1983). This model was based on the purely statistic data that were collected in the late 1970s and early 1980s.

It has been found that many factors affect the vehicle-utility pole accidents but the major factors that have been identified are travel speed, utility pole density, pole offset, and average daily traffic volume. A systematic study of the pole accidents was not available. Speed is obviously an important factor causing motor vehicle accidents. The previous research did not show any special effort on this part due to the general idea that ADT compromised the speed factor in accident analysis.

The literature review concludes that most of the studies performed earlier are uniquely based on the accident data. The products of the earliest studies are the results of the statistical best fit or regression. This kind of research is strictly limited, however, by the quality and range of the collected data. The lack of physical concepts in these studies always leads to some doubts once the actual conditions are different from the requirements of model application.

The relationships between vehicle-utility pole accidents and other causative factors need to be identified since the old model

encounters the fact that most of the vehicle accidents are caused by exceeding speed.

In addition, the review of a study of perception-reaction time (PRT) provides some important information to the vehicle-utility pole accident study. The PRT can be used to explain the effect of travel speed on utility pole accidents. Using PRT in the accident analysis will make the utility pole accident study more comprehensive. Since the PRT relates to the pole spacing and travel speed closely, the next chapter provides some quantitative analysis on the vehicle-utility pole accidents.

Table 2.1: Accident costs.

Description	Damage Cost
Fatal	$2,600,000
Incapacitating	$180,000
Evident	$36,000
Possible injury crash	$19,000
Property damage only (PDO)	$2,000

source: *Motor Vehicle Accident Costs*, FHWA, 1994.

CHAPTER 3
VEHICLE TRAVEL SPEED AND UTILITY POLE DENSITY

Introduction

This chapter deals with vehicle travel speed and the density of utility poles. The relationship between speed and utility pole density has been a concern for a long time. Previous researchers (Zegeer 1986, Hall, Burton, Coppage and Dickinson 1976, Jones and Baum 1980) realized that the travel speed is one of the most important factors causing pole accidents but without any quantity analysis due to the limitation of the data. For example, the data collected along the roadway sections are posted speed limits; and it is well known that drivers traveling at 5 to 10 mph exceeding the posted speed limits is very common. To find the true speed of a crashed vehicle before accident is intangible. It is impossible to get the real crash speed although the crash reconstruction speed data can be used. The crash reconstruction is only conducted for very severe traffic accidents; it cannot represent all travel speed (Liu 1996). Therefore, the data source limited the statistical analysis.

After reviewing international experiences on speed and collision and analyzing the speed-collision relationships on Saskatchewan (Canada) provincial highways, Liu (1996) found that the traffic accident severity of collisions increases dramatically with increase in vehicle travel speed. Liu also concluded that every 1

km/h reduction in average speed can result in 7 percent reduction in casualties and that 60 percent of all human errors and 40 percent of all casualty collisions in Saskatchewan may be speed related. The average travel speed are closely correlated to traffic casualties and casualty rates on Saskatchewan provincial highways. Liu (1996) and Lave (1995) found that speed differentials are correlated to the casualty rate. They concluded that the higher speed differentials also lead to more casualties.

This chapter explores the relationship between speed and utility pole density since dimensional analysis shows that the pole density affects the vehicle-utility pole accidents jointly with speed. This will be demonstrated in the next chapter. The next section uses the perception reaction time (PRT) to illustrate how speed can affect the vehicle-utility pole accidents.

Perception-Reaction Time

The perception-reaction time is the measurement of a driver's reaction time interval between the time he perceives an emergency event and the time of an action when he steps on the brake pedal.

How does the speed affect the utility pole accident? It can be demonstrated by combining the average PRT with travel speed and utility pole spacing. First, this paper reviews the simple relationship between travel speed and risk distance (RD). The risk distance is defined as the linear measure of a distance from one point at which a driver realizes something is wrong (car is off the roadway or perceives a dangerous object such as a utility pole in his

approaching direction) to another point at which he manages to avoid an accident under an urgent condition. Except for the travel speed and a person's reaction time, the geometric design affects risk distance, too. The shorter the risk distance, the quicker the driver's response will be or the better a driver can manage an emergency.

In a laboratory simulation, brake reaction times are obtained by measuring the time it takes someone sitting in a car-like environment to step on a brake pedal in response to a simple signal (e.g., a red light display). Across a variety of these brake pedal reaction time experiments, the finding has been a typical mean time of about a half second (Lerner et al. 1990). In the lab simulation, the brake reaction time for most persons ranges from one-half to three-fourths of a second (Lerner et al. 1995).

For the perception reaction time on the road, experiments in which the subject is alerted to the possibility of the need to brake, Lerner et al. (1995) found the response times briefer than in studies with unalerted subjects. In one of the most widely cited studies using alerted subjects, a median time of 0.66 seconds was obtained, with a mean of about 0.75 seconds, a 95 percentile of about 1.2 seconds, and a range of about 0.3 to 2 seconds (Johansson and Rumar 1971).

Using crash barrels to simulate the object for emergency events on road study, Lerner et al. (1995) concluded that more substantial steering action was associated with somewhat longer brake reaction times. Those drivers showing slight or no swerve and also braking had a mean brake reaction time of 1.44 seconds. Those showing more

distinct or severe swerves and also braking had a mean brake reaction time of 1.7 seconds. Thus, those who reacted to the emergence of the barrel with a more pronounced steering action also took about a quarter-second longer to activate the brake. Based on the perception-reaction experimental results (Lerner 1995), Table 3.1 presents the risk distances for various travel speed.

Table 3.1:Travel speed and risk distance (RD) for various brake reaction time in lab test

Travel Speed (mph)	Median RD (feet) (PRT=0.66 sec.)	Avg. RD (feet) (PRT=0.75 sec.)	95 Percentile RD (feet) (PRT=1.2 sec.)
35	34	38	62
40	39	44	70
45	44	49	79
50	48	55	88
55	53	60	97
60	58	66	106
65	63	72	114
70	68	77	123
75	73	83	132
80	77	88	141
85	82	94	150

The same report (FHWA-RD-93-168) indicated that the average PRT is 2.0 seconds. The shortest and longest ones are 1.4 seconds and 2.5 seconds, respectively. Using the concept of risk distance, Table 3.2 lists the values for various travel speeds. The same concept and methodology can be used for other fixed object accident analyses.

Table 3.2: Relationship between travel speed and risk distance (RD)

Travel Speed (mph)	Lower bound of RD (feet) (PRT=1.4 s)	Average RD (feet) (PRT=2.0 s)	Upper bound of RD (feet) (PRT=2.5 s)
35	72	103	128
40	82	117	147
45	92	132	165
50	103	147	183
55	113	161	202
60	123	176	220
65	134	191	238
70	144	205	257
75	154	220	275
80	164	235	293
85	175	249	312

The risk distance is the measure of the minimum distance that a driver needs to avoid hitting the pole at a certain travel speed. For example, a given car is traveling at a speed of 50 mph, assume that a driver's perception-reaction time is average, 2.0 seconds. Due to human error, the car runs off the roadway and in the direction of hitting a fixed object, such as a utility pole or a tree. In order to avoid hitting the object, the driver must be at least 147 feet away from that fixed object. Otherwise it is impossible for him to avoid hitting the pole.

Speed and Accident

55 mph Speed Limit History

To conserve fuel during the oil crisis in 1974, the national 55 mph speed limit was imposed. Traffic slowed down on all major highway systems in the United States. It was concluded (TRB 1984) that up to 4,000 lives were saved and about the same number of fewer serious injuries every year during the 10 years (1974-1983) of the imposed 55 mph speed limit. But in 1987, each state was allowed to raise speed limits on the rural interstate freeways up to 65 mph. It was reported (U.S. Transportation Department 1992) that average travel speeds on these rural interstate highways have increased from 60.6 mph in 1986 to 64.0 mph in 1990, and the percentage exceeding 70 mph has increased from about 6 percent to 19 percent. Fatalities were 30 percent higher on the rural interstates in the 38 States that increased the speed limit to 65 mph than might have been expected from historical trends.

The 1994 federal speed cap was abolished in 1995. Some states have increased their speed limits, such as 70 mph along some sections of I-75. The speed limit increases are for mobility reasons, not for safety purposes. The same differential speed or overspeed, such as 5 to 10 mph, at high speed travel impacts the accident involvement, and accident severity will be different from that of lower travel speeds, such as below 30 mph of travel speed. The principle of physics states that the momentum of a moving body is proportional to its moving

speed and the kinetic energy is proportional to the square of its moving speed. This speed impact on safety remains to be seen.

Other Countries' Experiences with Speed and Safety

In Australia, the Victoria government raised the speed limit on its rural and outer Melbourne freeway network to 110 km/h from 100 km/h in 1987. The 100 km/h was reinstated after two years. The casualty rate increased by 24.6 percent during the two years, and decreased 19.3 percent after the 100 km/h speed limit was reinstated (Sliogeris 1992).

A recent report (U.S. Insurance Institute for Highway Safety, 1995) indicated that the death rates on the German autobahns (which used to have no speed limits) has been higher than that on the U.S. interstate highways (which have speed limits) over the last 20 years with the exception of the three years after the United States raised the speed limit to 65 mph. Many European countries found that traffic collisions increased when speed limits increased (TRB 1984 and Fildes 1993).

G.X. Liu (1996) studied the relationship between speed and accidents in two issues. He examined the relationship between speed and severity of accidents and also the relationship between speed and accident involvement. Liu found that higher travel speeds lead to a dramatic increase in accident severity. Charles Lave (1995) found that the major factor is not average speed but rather the variation in speed among cars. Differential speeds cause more turbulence in the traffic stream--passing and overtaking. He claimed that variance kills, not speed. What matters most in setting a speed limit is

choosing a limit that drivers will obey in order to reduce the variation in speed among cars.

To search the optimum speed limit based on the variation of travelers is not a simple task. Some argue that if the speed variance can be kept down when increasing speed limits then traffic safety will not be affected. The most important question remains: What is the relationship between average speed and speed variance? If the speed does not kill, could the speed be increased while keeping the speed variance down? A researcher (Garber 1989) suggests that speed variances will decrease with the increase of average speeds. This obviously contradicts the results of speed limit change. As some researchers (Liu 1996) point out, both speed and speed variance affect the accident and typically the human factor includes many speed-related errors, which are the most prevalent source of human errors. The human factor accounts for 66 percent of all collisions and more than 80 percent of fatal collisions. If considering five types of errors as speed related--too fast, exceeding speed limits, following too closely, failing to yield, disregarding traffic control device--Liu's data show that more than 60 percent of all drivers' errors are speed related.

Vehicle-Utility Pole Accidents

The vehicle-utility pole accident is a single vehicle accident. On Saskatchewan provincial highways (Canada), statistical results show that about 60 percent to 80 percent of collisions are single vehicle collisions (Liu 1996). In other words, lane changing and

overtaking are not factors. Most persons drive at a speed they perceive to be safe. However, this suitable driving speed is different for each person because everyone has his own perception and different physical and mental conditions. There is no uniform suitable driving speed that satisfies everyone on every road. The experimental data (FHWA-RD-93-168) about the study of perception-reaction time (PRT) provides the same results.

Table 3.2 lists the calculated results based on the PRT and travel speed. Where the lower bound, upper bound and the average risk distances are calculated according to the shortest PRT (1.4 seconds), the upper bound of PRT (2.5 seconds) and the average value of PRT (2.0 seconds). For most suburban areas, the speed limits of 40 mph to 45 mph are very common. From the Table 3.2 the risk distance is 132 feet for the average PRT. So if the utility pole density is 40 poles per mile in a section, which equals 5,280 feet divided by 132 feet, this section should be classified as fully potential risk area. That means, for any run-off-road vehicle, a driver cannot avoid hitting a pole in this section if he is traveling at the speed no less than the proposed travel speed in the first column of the table. But this does not mean that if pole spacing is larger than 132 feet, a driver can avoid hitting a pole since he may run off the road in between poles.

CHAPTER 4

UTILITY POLE ACCIDENT RATE PREDICTIVE MODEL BY DIMENSIONAL ANALYSIS

Introduction

Florida has one of the worst records for numbers of traffic accidents. Utility pole accidents play one important role in the total fatality number. According to the data of the Fatal Accident Reporting System, the National Summary of Utility Pole Fatalities indicates that from 1990 to 1993, Florida ranks sixteenth in the number of fatalities per 100 billion vehicle-miles of travel and fifth in the total number of such fatalities. The total number of fatalities caused by hitting utility poles is 5,009 in the nation. The number in Florida accounts for 5.9 percent with a total of 297 fatalities (FHWA 1995).

To reduce the frequency and severity of utility pole accidents, this researcher's aim is to make the most efficient use of countermeasures and enhance the usefulness of the previous study results about utility poles. The research pinpoints the most deficient roadway sections from the total accident number, accidents per mile per year (rate of accident), and the severity conditions. Alternative ways exist to correct the utility pole location problems. The most common methods of countermeasures were mentioned earlier. They include (Zegeer and Cynecki 1986):

- placing utility lines underground
- relocating the most dangerous poles

- increasing the distance between utility pole and the edge of roadway
- using breakaway poles
- increasing the pole distance or space between utility poles

The principles of these countermeasures have been detailed by Zegeer and Parker (1986).

This chapter summarizes the study methods for the ongoing research. The research identifies the factors that relate to vehicle-utility pole accidents and investigates the model for vehicle-utility pole accidents rate prediction developed by Zegeer et al. The method of dimensional analysis is applied to check the model. The analysis reveals that the speed factor was missing in Zegeer's model. The speed should be integrated into the predictive model and affect the vehicle-utility pole accident rate jointly with utility pole density. This finding is consistent with the conclusions about the effect of travel speed on accidents from other authors (Liu 1996, TRB 1984, Fildes 1993 and Sliogeris 1992).

As stated in previous chapters, 55 percent of the utility fatalities occurred on high-speed roads and the exceeding speed is a main cause of vehicle-utility pole accidents. Due to the lack of travel speed in Zegeer's model, it is difficult to explain these facts. In addition, the limits of 500 to 60,000 ADT make his model inapplicable to many roadways in Florida where the ADTs exceed the 60,000 limit. Therefore, it is necessary to develop a new model.

This chapter presented a new research methodology which combines the ideas of dimensional analysis and statistical knowledge. It also explored the relationship between pole accident rate and

other major factors such as pole density, vehicle speed, ADT, and pole offset. The use of dimensional analysis resulted in a concrete frame of the model formulation.

New Model Development

Identification of Critical Model Parameters

A study conducted by I.S. Jones and A.S. Baum (1980) indicates that utility pole accidents have the highest rate of injury involvement of all single-vehicle accident types. The density of poles was found to be the most important factor which relates to utility pole accidents. Other important factors such as road width, speed limit, and average daily traffic volume were also found to be related to utility pole accident occurrence. In a 1976 evaluation of 19,743 single-vehicle, fixed-object accidents, Hall et al. (1976) found that one of the major factors associated with this accident type was the lateral placement of roadside obstacles. By using comparative analysis, Zegeer and Parker (1983) found that the mean numbers of utility pole accidents are significantly affected by the average lateral pole offset, traffic volume, and pole density. It has been found that a significant interaction exists between other factors, such as state, area type, roadway classification, pole type, and speed limit (Zegeer et al. 1983). Based on historical accident data, a predictive model was developed by using the best-fit regression and correlation analysis. The model can be used to forecast the utility pole accident rates by inputting traffic volume, pole density, and offset. The road conditions, pole

characteristics, speed limit, and vehicle size were all recognized as important factors. The pole offset of distance from the edge of the road was found to be significant when it was within 10 feet (Zegeer and Parker 1983).

Traditional Model

The literature search resulted in identifying two models that could be used for the vehicle-utility pole accident prediction. One is binomial regression method and another is a predictive model developed by Zegeer et al. in the 1980s.

The first one is classified into the Poisson's Distribution and Negative Binomial Regression. The Poisson's Distribution is a formula of binomial distribution under an extreme case, such as complete random events with large sample sizes and a small probability of events. Therefore, Poisson's Distribution is adequate for single-vehicle accidents and fixed-object accident predictions. For instance, if the average number of accidents for a specific roadway section in a specific time period is denoted as *p*, then its variance will also be *p*, and standard deviation is the square root of *p*. This model can be used to predict the average frequency of accidents with a certain probability, but it will not tell how to improve the roadway deficiency.

The negative binomial regression is an improved binomial regression. The principle of this method is the same as that of Poisson's Distribution. For example, if the utility poles are moved farther away from the edge of road, the binomial regression method will not be able to quantitatively provide the effect of the roadway

improvements, or the reduction of the utility pole accidents due to the roadway improvements. Thus, it cannot be used in the project ranking.

Another one is a utility pole accident predictive model developed by Zegeer et al. (1983), which states:

$$F_{acc} = \frac{9.84x10^{-5}\ (ADT) + 0.0354\ (DEN)}{(OFF)^{0.6}} - 0.04 \qquad (1)$$

where: F_{acc} = The number of vehicle-utility pole accidents per mile, per year

DEN = The number of utility poles per mile

OFF = Average utility pole offset (in feet)

ADT = Average daily traffic volume

Note: 1 m = 3.28 feet; 1 km = 0.62 mile; 1 pole/km = 1.61 pole/mile

1 accident/mile/year = 0.62 accidents/km/year

This model was developed based on the accident, traffic, and roadway data collected from more than 4,025 km (2,500 miles) of urban and rural roads in four states (Colorado, Michigan, North Carolina, and Washington). It is a purely statistical regression formula of early 1980s data.

Using a comparative analysis, the lateral offset, average daily traffic volume and pole density were found to be most highly associated with utility pole accidents. Since any given roadway section has unique characteristics in terms of utility pole accident experience, state roadway regulations, driving habits, and other factors, this model has to be tuned according to a state's historical accident data. Although speeding is a well-known factor that

Table 4.1 Summary of crash data in districts 1, 4, 5, 6 and 7 of Florida (1991-1993) (source: FDOT Safety Office)

Accident severity	Number of accident	Percent of the total accidents	Number of people injured	Number of people killed	Injured per accident	Killed per accident
PDO accident	1,746	35.04	0	0	0	0
Injury accident	3,120	62.61	4,698	0	1.5058	0
Fatal accidents	117	2.35	116	136	0.9915	1.1624
Total accidents	4,983	100	4,814	136	0.9661	0.0273

contributes to traffic accidents, this factor is compromised by average daily traffic volume in previous research.

To summarize the vehicle-utility pole crashes in Florida, Table 4.1 shows the tabulated pole crashes in five districts from 1991 to 1993.

From the bottom row of the table, It can be seen that fatalities per each vehicle-utility pole accident is 3 percent and injuries is 97 percent. This means from 1991 to 1993 on Florida roadways, an average of three people were killed for every 100 crashes--almost one person injured for every crash. 35.04 percent of the accidents are property damage only (PDO), injury accidents account for 62.61 percent, fatal accidents account for 2.35 percent.

As mentioned before, Zegeer's model is a purely statistic formula and its development is based on the accident data collected before 1983. It cannot guarantee the reliable results for the situation that is out of its limitations. The range of average daily traffic (ADT) volume in the model is far below the ADT encountered on many Florida roadways. For instance, the collected data show that

ADTs along many sections on the Florida roadways from 1990 to 1993, are beyond the value of 60,000 of the maximum limits for traditional model; along the Section 75280000 (Orange County, District 5) of State Road R400, the ADTs range from 108,687 to 176,655. This indicates that the method of extrapolation has to be used for the traditional model and, therefore, the predicted accident rate could be unrealistic if one decided to use that model under this high ADT condition. In addition, the current traffic situation is much different from that of 10 years ago. The car model and the combination of the traffic flow have changed dramatically in recent years. Thus, this statistical model cannot provide reliable results due to these changes in more than 10 years. Therefore, a reasonable model or a new model should be developed to predict the utility pole accidents, at least for the Florida situation.

Development of a New Predictive Model

As stated previously, the pole density, average daily traffic volume, the lateral offset, and speed limit are identified as the major factors that relate to pole accident frequency. Therefore, the expected form of an accident predictive model can be described in general as follows:

$$R_a = f\ (\mathrm{DEN},\ \mathrm{SPD},\ \mathrm{ADT},\ \mathrm{OFF},\ \ldots) \qquad (2)$$

where:

DEN = pole density (poles per mile);

SPD = travel speed or over speed[1] (mph);

[1] The difference between driving speed and posted speed limit; some researchers use the name " differential speed."

ADT = average daily traffic volume (car per day;

OFF = the offset of pole line from the edges of road (feet);

f represents certain relationships between accident rate R_a and other causative factors, such as pole density (DEN), speed (SPD), ADT and offset (OFF).

Principle of Dimensional Analysis

The principle of the dimensional analysis method is that the dimensional units of the left-hand side of the predictive model must be consistent with the right-hand side.

Many typical applications and discussions of dimensional analysis in engineering, physics, and astrophysics can be found in many references (Bridgman 1922, Kurth 1972 and Taylor 1974). For the theory of dimensional analysis one can refer to Dimensional Analysis in the Identification of Mathematical Models, by Kasprzak, Lysik and Rybaczuk (1990). To conduct a dimensional analysis the following procedure is used:

- List all the quantities on which the answer may depend
- Write down the dimensional formulas of these quantities
- Develop a dimensional model by substituting the dimensional formulas for each factor (in the proposed model). In this case, the dimensional formulas of accident rate, utility pole density, average daily traffic volume, utility pole lateral offset distance, and driving speed are used.

In the dimensional formulas the symbols of accident rate (R_a)[2], pole density (d), average daily traffic volume (k), utility pole

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[2] Use Ra to represent the utility pole accident frequency to distinguish from Zegeer's model.

lateral offset (ℓ), vehicle speed[3] (v), and time period (t) will be denoted by capital letters and raised to proper powers; for example, the capital letter "L" is used for utility pole lateral distance or other length measurements and "T" for time, respectively. Table 4.2 lists the fundamental quantities, their symbols and related dimensional units.

The problem at hand is to find R_a as a function of k, d, ℓ and v, so that the functional relation still holds true when the size and combinations of the fundamental dimensional units included in the model are changed in every conceivable way. Suppose that this functional relation has been found:

$$R_a = f\ (d,\ k,\ \ell,\ v) \tag{3}$$

Table 4.2:Fundamental quantities and their dimensions

Name of Quantity	Symbol	Dimensional Formula
Accident frequency	R_a	$L^{-1}\ T^{-1}$
Pole density	d	L^{-1}
Average daily traffic volume	k	T^{-1}
Lateral offset	ℓ	L
Speed limit	v	$L\ T^{-1}$

In order to simplify the analysis, R_a can be expressed using two components: f_1 and f_2, i.e.,

$$Ra = f_1\ (d,\ v,\ \ell) + f_2\ (k,\ \ell) \tag{4}$$

where the effects of the utility pole density and vehicle speed are separated from the effect of ADT on the accident rate. The lateral offset distance of the utility pole enters both terms because it is

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3 For the dimensional analysis, speed limit, vehicle speed, the difference between road design speed and posted speed have the same meaning. Here the term "speed" is used without loss of generality.

perceived that the offset will trade off all other effects on the utility pole associated with the accident rate. The necessity for separating the effects of the utility pole density and speed from the effect of ADT on the accident rate is demonstrated in the following section.

Identify the Functional Form of Utility Pole Accident Rate

Suppose the model has the following form (Bridgman gave a good explanation and demonstrated the reason for the dimensional units of the model factors being raised to powers):

$$Ra \propto d^{\alpha} k^{\beta} \ell^{\gamma} v^{\lambda} \tag{5}$$

Then, using the dimensional formula in Table 4.2,

$$L^{-1}T^{-1} = (L^{-\alpha})(T^{-\beta})(L^{\gamma})(L^{\lambda}T^{-\lambda}) \tag{6}$$

Where α, β, γ and λ are integer numbers.[4] The symbol "$\propto$" is read as "directly proportional to." This implies that,

$$-\beta-\lambda=-1 \tag{7}$$

$$-\alpha+\gamma+\lambda=-1 \tag{8}$$

through rearranging terms and substitution,

$$\beta+\lambda=1 \tag{9}$$

$$\alpha+\beta-\gamma=2 \tag{10}$$

Since there are four unknown quantities and only two equations of condition, two arbitrary values exist in these equations.

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4 P.W. Bridgman gave a good reason and demonstrated why the dimensions of quantities always go to powers.

In order for the independent factors d, k, ℓ, and v to all be represented in the functional model, $R_a \propto d^{\alpha}k^{\beta}l^{\gamma}v^{\lambda}$, and knowing that accident rates are directly proportional to the speed of the vehicle, the following constraints on the parameters α, β, γ, λ must hold true,

$$\alpha \neq 0 \tag{11}$$

$$\beta \neq 0 \tag{12}$$

$$\gamma \neq 0 \tag{13}$$

$$\lambda > 0 \tag{14}$$

However, according to equation (9) above,

$$\beta + \lambda = 1$$

Therefore,

$$\beta = 1 - \lambda \tag{15}$$

but, it is known from equation (14) that,

$$\lambda > 0$$

Examining equation (13), this would imply that

$\beta < 0$ (since $\beta \neq 0$, from equation (12).

This result ($\beta < 0$) is a contradiction to one of the most basic dimensional formula constraints (for the functional relationship combination, $R_a \propto k^{\beta}$, k being the ADT) given by,

$$L^{-1}\,T^{-1} \propto T^{-\beta} \tag{16}$$

where $\beta > 0$ is the expected value.

This contradictory result indicates that the effect of ADT (k) cannot be combined with the other three factors d, ℓ, and v to form a single functional component for predicting accident rates. It is therefore necessary for other combinations of the predicting factors

to satisfy the constraints imposed by the dimensional analysis formulas.

Examining other functional component combinations, there are

$$R_a \propto d^{\alpha} k^{\beta} v^{\lambda} \quad (17)$$

and

$$R_a \propto \ell^{\gamma} \quad (18)$$

using the dimensional formulas in Table 4.2,

$$L^{-1} T^{-1} = L^{-\alpha} T^{-\beta} L^{\lambda} T^{-\lambda} \quad (19)$$

and,

$$L^{-1} T^{-1} = L^{\gamma} \quad (20)$$

From (19) we get,

$$-\alpha + \lambda = -1 \quad (21)$$

$$-\beta - \lambda = -1 \quad (22)$$

Rearranging the terms in equation (21),

$$\alpha = 1 + \lambda$$

Therefore,

$$\alpha > 0 \text{ (since } \lambda > 0)$$

Similarly, rearranging the terms in equation (22),

$$\beta = 1 - \lambda$$

Therefore,

$$\beta < 0 \text{ (since } \lambda > 0 \text{ and } \beta \neq 0)$$

Once again, this result ($\beta < 0$) is a contradiction to the dimensional equation constraint (16) where $\beta > 0$ is the expected value.

This indicates that the effect of ADT (k) cannot be combined with the two factors, utility pole density (d) and speed (v), to form

a single functional component for predicting accident rates. In other words, the effect of ADT (k) on accident rates must be considered separately from the effects of utility pole density (d) and speed (v).

These preliminary dimensional analyses point to the need for the two separate functional components given in equation (4) for predicting vehicle-utility pole accident rates. The following two sections identify the parameter formulations within the two functions, f_1 and f_2, through the use of the dimensional analysis method.

Find the Components of f_1 and f_1 Using Dimensional Analysis

For the contribution of the functional component, f_1, in (4) the dimensional analysis method demands that the dimensional formula of the dependent variable (R_a) equals the dimensional formula for f_1. That is,

$$[\ Ra\ ] = [\ d^{\alpha}\ v^{\beta}\ \ell^{\gamma}\ ] \tag{23}$$

where the brackets mean the resultant dimension of that quantity. Therefore, using the dimensional formula for the respective factors in Table 4.2, the dimensional equation is

$$L^{-1}\ T^{-1} = L^{-\alpha}\ (L\ T^{-1})^{\beta}\ L^{\gamma} \tag{24}$$

Comparing both sides, we have

$$-\alpha + \lambda + \gamma = -1 \tag{25}$$

$$-\lambda = -1 \tag{26}$$

Solving these linear equations, we have

$$\lambda = 1 \quad (27)$$

$$\alpha - \gamma = 2 \quad (28)$$

From (28) it can be seen that there are two unknown parameters, α and γ, within the same equation that relates to them. Therefore, one of the parameters is arbitrary.

Therefore, setting $\alpha = x$, the functional formula is

$$f_1\ (d,\ v,\ \ell) = d^x\ v\ \ell^{\,x-2} \quad (29)$$

Simplifying, we get

$$f_1\ (d,\ v,\ \ell) = (l \cdot d)^x\ v\ /\ \ell^{\,2} \quad (30)$$

From (24) one can see that γ is expected to be a negative number and α a positive number. These constraints satisfied for $x = 1$. Therefore setting $x = 1$ yields,

$$f_1\ (d,\ v,\ \ell) = d \cdot v\ /\ \ell \quad (31)$$

Through the application of the dimensional analysis method (as in the previous two sections), it is possible to examine whether valid formulations exist between the f_2 function factors k and ℓ for predicting accident rate, R_a. From (4) it is perceived that the accident rate, R_a, is proportional to f_2 comprised of the factors k and l. Therefore,

$$R_a \propto f_2(k,\ \ell) \quad (32)$$

where,

$$f_2(k, \ell) = k^{\beta} \ell^{\gamma} \tag{33}$$

Now, using the dimensional formulas from Table 4.2, the dimensional equation is,

$$L^{-1} T^{-1} = T^{-\beta} L^{\gamma} \tag{34}$$

Therefore, the values of the parameters are,

$$\beta = 1$$

$$\gamma = -1$$

Substituting these values of β and γ into the functional component f_2 (k, ℓ) yields,

$$f_2 (k, \ell) = k^1 \ell^{-1}$$

or,

$$f_2 (k, \ell) = k / \ell \tag{35}$$

With both functional components f_1 and f_2 now well defined (in terms of valid and consistent formulations of their respective factor dimensional units with respect to R_a dimensional units), the final form of the vehicle-utility pole accident rate prediction model is,

$$R_a = c_1 f_1 (d, v, \ell) + c_2 f_2 (k, \ell) + c_3$$

or,

$$R_a = c_1 (d v / \ell) + c_2 (k/ \ell) + c_3$$

or,

$$R_a = (c_1 d \cdot v + c_2 k) / \ell + c_3 \tag{36}$$

where,

c_1 and c_2 are dimensionless constants,

c_3 is a dimensional random variable (error term) which has the same dimensions as that of Ra,

d is the utility pole density,

v is the vehicle speed,

k is the average daily traffic volume,

ℓ is the utility pole lateral offset distance.

The constants, c_1 and c_2, and the random variable error term, c_3, can be determined by calibrating the model using statistical regression analysis methods based on empirical accident, traffic, and roadway data collected on vehicle-utility pole collisions occurring in the state. R_a is the resultant prediction of the vehicle-utility pole accident rate for a roadway section with the units of accidents per mile per year.

This relation shows that pole density and ADT affect the accident frequency separately. The product of speed and pole density should be considered as a whole effective factor to enter the model with the tradeoff of pole offset. If all quantities are kept as constants except the pole density and speed, then the factor of speed will be inversely proportional to the pole density. This is significant for safety analysis because it puts the pole density and speed together as a design factor. For example, assume the offset does not change, pole density is 70, design speed is 35 mph. In order to raise the speed, the pole density must be decreased so that the accidents related to pole will not increase.

Nonlinear Form of Vehicle-Utility Accident Predictive Model

As in previous sections, one can find that the dimensional analysis results in two dimensionless entities

$$Dim(\frac{d \cdot v}{l \cdot R_a}) = 0$$

or,

$$R_a = d \cdot v / l \tag{37}$$

and

$$Dim(\frac{k}{l \cdot R_a}) = 0$$

or,

$$R_a = k / l \tag{38}$$

It can been shown that the previous model is a linear combination of the two components above. For the nonlinear combination, the result is

$$R_a = \alpha \cdot \frac{\sqrt{d \cdot v \cdot k}}{l} + \beta + \varepsilon \tag{39}$$

Where α and β are constants, and ε is an error term; both α and β can be determined by accident experience and field data. The value of ε can also be estimated based on State accident experience and field data.

The parameters in this nonlinear formula will be determined by statistical method in the next chapter. Although the α and β are unknowns, the formula is able to provide some valuable information. Since β and the error term ε are not expected to be large, therefore, the changes of parameters in the formula can directly affect the predictive results. For instance, given a road section with pole density of 80 poles per mile and accident rate of 100 pole accidents

per year per mile, due to the relocation of pole line from an average of 2 feet to 4 feet, it is expected to reduce the accidents by half or 50 accidents. The accident reduction factor is ($1- \ell_1 / \ell_2$), where the ℓ_1 and ℓ_2 are the pole offsets before the pole relocation and after pole relocation, respectively. Reducing the pole density by half or changing pole density from 80 poles per mile to 40 poles per mile will result in 29 accidents reduction. The reduction factor for changing pole density is

$$1-\sqrt{d_2 / d_1}$$

Where d_1 and d_2 are the utility pole densities of before correction and after correction, respectively.

It must be noticed that the different terms of speed can be used in the model. The effect of driving speed on the accident rate is different from that of the posted speed because a person may drive a speed higher than the posted speed limits. For instance, someone may drive 60 miles per hour while the posted speed is 35 mph. The overspeed is 25 mph. This overspeed is argued as the main factor claiming driver and passenger lives. Since the speed limits along most of the roadways are decided by 80 percentile of the traffic, the difference between an individual driver and the main flow of travel stream plays an important role in predicting the accident rate. As Charles Lave (1995) pointed out it is the few high speed vehicles that cause the turbulence of travel stream and which therefore results in collision accidents; it is not the fault of posted speed or uniform travel flow. However, the posted speed sets the average flow speed or the mean of the driving speed.

Alcohol is another reason that causes an accident since it can impair a driver's response between sighting and reaction. The main purpose of locating the pole in a reasonable distance from the roadway is to give the driver more space and time for recovery once he runs off the road. The reduction of pole density reduces the event chance (or the total number of vehicle pole intersections) and provides more recovery time and space for the driver since continuous fixed hazard will give him no chance to avoid pole-hit accident once he runs off the roadway.

Discussion of the New Model

The formula (39) is a nonlinear combination form of the

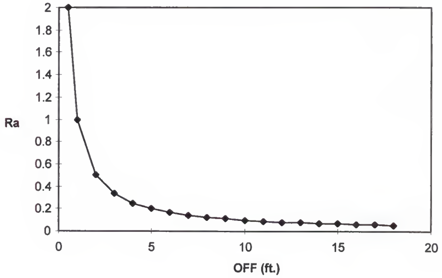


Figure 4.1: Accident Rate R_a vs. Pole Offset OFF (OFF = ft).

accident predictive model where ε is an error term and β is a constant that is expected to be very small. R_a is inversely proportional to pole offset ℓ and is proportional to the square root

of the product of pole density, speed, and ADT. From Figure 4.1 it can be seen that pole offset, OFF, is a very sensitive factor that affects the accident rate R_a as it (OFF) is less than 5 feet.

This nonlinear model can also be used for the purpose of pole safety improvements. If the accident experience of a specific road section is known, the reduction, due to the changes of offset or pole density and ADT, can be calculated directly from their relationships (39), as illustrated in the previous section. For instance, a given section has an average of 5 pole hit accidents per year per mile. After relocating the poles from 2 feet (before) to 8 feet (after), the accident reduction factor due to the roadway improvement will be $(\ell_2 - \ell_1)/\ell_2$ and the reduction will be 5 - 5 x 2/8 = 3.75 pole

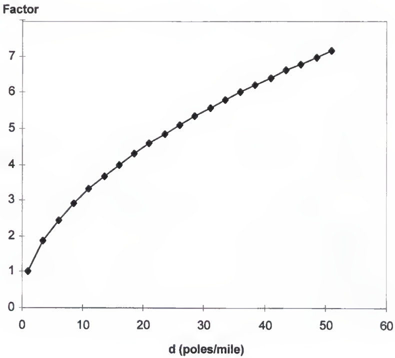


Figure 4.2: Effect of Pole Density on Accident Rate R_a.

accidents. Knowing the pole accidents (actually all kind of vehicle accidents) are random events, the improvement of relocating poles can reduce the probability of pole hit accidents. In this case, the probability of the pole hit is one-fourth as before pole relocation.

Similarly, the reduction of pole density also affects the pole accident rate, but it affects the R_a in the form of square root. Figure 4.2 shows the relationship between accident rate and pole density d.

When dealing with the effect of pole density d (or DEN), the speed factor, v (or SPD) and the average daily traffic volume k (or ADT) cannot be ignored. The speed and ADT affect the accident rate R_a in the same way as that of pole density. It can be seen that reducing pole density results in the decrease of accident rate. For instance, reducing pole density from 64 poles per mile to 32 poles per mile results in the decrease of accidents by a factor 0.29. Although this is not as sensitive as that of changing pole offset, it is a very sensitive factor after being scaled by factors of speed and ADT. This kind of improvement is based on the principle of reducing the total number of intersections between traffic and poles. Statistically, the increase of vehicle-pole intersections will result in more chance for the pole-hit accidents. The principle of the pole density affecting the accident rate acts as the same way as scan process. Therefore, as the density of poles increases, the scan rate also increases. To some extent the poles will become a continuous obstacle (as a wall) for certain driving speeds. On the other hand, for a certain pole density, increasing the driving speed to some extent will also result in facing a continuous hazard. Therefore, the product of pole density

and speed can be a very important factor that affect the pole accident rate. In order to measure the risk of poles along roadways to the traffic, this product, pole density times the travel speed, or $d \cdot v$, is referred to as risk factor (RF) in later chapters.

Using overspeed instead of driving speed results in a more sensitive speed factor. Generally, most of the vehicles travel around the posted speed limits; this condition creates smooth traffic flow. Research conducted by Charles Lave (1995) indicates that the main cause of traffic accidents is not caused by speed but by the cars that disturb the smooth flow of traffic. Next, the discussion will focus on how the overspeed affects the accident rate, R_a.

If average traffic travel flows at 40 mph along a roadway with a posted speed limit 35 mph, which is very common across the United States, the overspeed is 40 - 35 = 5 mph. If this number (5 mph) is used as the base number of input in the formula (39), for an overspeed of 15 mph (driving at 50 mph under the same posted speed limit) the risk of accidents will increase 1.72 times as that of overspeed of 5 mph (or driving speed of 40 mph) under posted speed limit of 35 mph. But if the speed 40 mph is used in the formula, driving 50 mph will only increase the risk of the square root of 50/40, which is 1.1 times of the case in which the average driving speed 40 mph is set as the base input speed in (39) while speed limit is 35 mph. Therefore, it is possible to use the overspeed to measure the danger or risks of vehicle-pole accidents instead of using driving speed or speed limits.

For engineering practice, Table 4.3 lists the reduction factors of various pole offsets for before correction and after correction.

From the expression of R_a, it can be seen that the vehicle speed (SPD) combined with the utility pole density affects the accident frequency. The model states that vehicle speed is proportional to the utility pole accident rates. Higher travel speed will results in higher risk of fixed object accidents. That means the chance of an accident will be reduced properly if a driver can keep his speed under the proper posted speed limits. The model provides that the vehicle speed is critical for certain roadway conditions, such as roadway surface, curvature, weather. This is significant because the probability of event depends on both driver (driving speed) and engineer (roadway design speed and posted speed setting).

Table 4.3: Accident rate reduction factors due to pole relocation (before and after roadway correction).

	Pole Offset (OFF) Before Relocation (ℓ_1 feet)									
OFF After Relocate, ℓ_2	1	2	3	4	5	6	7	8	9	10
1										
2	0.500									
3	0.667	0.333								
4	0.750	0.500	0.250							
5	0.800	0.600	0.400	0.200						
6	0.833	0.667	0.500	0.333	0.167					
7	0.857	0.714	0.571	0.429	0.286	0.143				
8	0.875	0.750	0.625	0.500	0.375	0.250	0.125			
9	0.899	0.778	0.667	0.556	0.444	0.333	0.222	0.111		
10	0.900	0.800	0.700	0.600	0.500	0.400	0.300	0.200	0.100	
11	0.909	0.818	0.727	0.636	0.545	0.455	0.364	0.273	0.182	0.091
12	0.917	0.833	0.750	0.667	0.583	0.500	0.417	0.333	0.250	0.167
13	0.923	0.846	0.769	0.692	0.615	0.538	0.462	0.385	0.308	0.231
14	0.929	0.857	0.786	0.714	0.643	0.429	0.500	0.429	0.357	0.286
15	0.933	0.867	0.800	0.733	0.667	0.600	0.533	0.467	0.400	0.333

Note: The reduction factors are calculated as $(1- \ell_1 / \ell_2)$.

By comparing the general form of R_a, which results from the dimensional analysis, with F_{acc} of Zegeer's model, one can see that the power of utility pole offset, 0.6, disappears. This is a fundamental difference between the two models. The existence of a fractional power on the utility pole offset (OFF) is not acceptable because it is one of the fundamental predictive factors in the model.

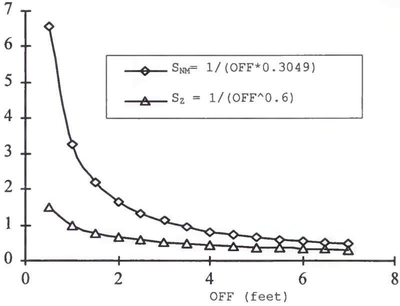


Figure 4.3: Sensitivity Comparisons for Utility Pole Offset Factor Effects in the "New Model" and Zegeer's Model.

Note: S_{NM} and S_Z are the comparable sensitivity effects of utility pole offset factors in the new model and Zegeer's model, respectively.
1 feet = 0.3049 meters.

It (OFF) should follow the manipulation rules in operation with other terms and the result should be interpretable as described by some scientists (P.W. Bridgman, pp. 45-46, S.P. Thompson, p. 352 and W. Williams 1892):

> "It is often felt that the dimensional formula of a quantity should not involve the fundamental quantities to fractional power." -- P.W. Bridgman

"It also seems absurd that the dimensions of a unit of electricity should have fractional powers, since such quantities as $M^{1/2}$ and $L^{1/2}$ are meaningless." -- S.P. Thompson

"So long, however, as L, M, and T are fundamental units, we cannot expect fractional powers to occur. . . . Now all dynamical conceptions are built up ultimately in terms of these three ideas, mass, length, and time, and since the process is synthetical, building up the complex from the simple, it becomes expressed in conformity with the principles of Algebra by integral powers of L, M, and T. . . . Obviously if mass, length, and time are to be ultimate physical conceptions, we cannot give interpretations to fractional powers of L, M, and T, because we cannot analyze the corresponding ideas to anything simpler. We should thus be unable, according to any physical theory, to give interpretations to formulae involving fractional powers of the fundamental units." -- W. Williams

This change makes the utility pole offset predictive factor more sensitive to the prediction of vehicle-utility pole accident rate as the offset distances are smaller (approximately 3.5 feet or 1.07 meters). For example, the new model will result in a relative difference of 66.7 percent on offset factor OFF for relocating utility poles from 0.61 m (2 feet) to 1.83 m (6 feet) away from the edge of a roadway, but Zegeer's model will result in 48.3 percent. Figure 4.3 demonstrates the sensitivity comparison between the utility pole offset factor effects for the two models. S_{NM} represents the sensitivity effect of utility pole offset in the new model, and S_Z is the sensitivity effect of utility pole offset in Zegeer's model.

Summary

It is perceived that the speed of a vehicle is a major contributing factor causing traffic accidents. This is the primary reason that speed enforcement policies are implemented and that speed enforcement is one of the main road safety related tasks performed by

police officers. For these reasons it is important that the effects of vehicular speed on accident causation and its relationship with other determining factors are well understood.

The ADT does indirectly reflect some of the effect of posted speed limits on vehicle-utility pole accident rate, however, its effect cannot replace the direct effect of vehicle speed and utility density (as demonstrated in this study). The vehicle speed factor, therefore, should appear explicitly in models involving the prediction of vehicle-utility pole accident rates.

The results obtained by the dimensional analysis approach reveals that speed factor should enter the vehicle-utility pole accident predictive model jointly with the utility pole density factor to form a single combined component. This is separate from the ADT factor component effects in the linear model. Equation (36) is the simplified linear form of the final vehicle-utility pole accident predictive model, which complies with all required parameter constraints demanded by the dimensional analysis approach. Equation (39) is the result of nonlinear form from dimensional analysis. This is a very handy formulation which requires only the value of α to be determined by experimental data. Other constants, β and ε, can be assumed to be very small. The data collected in Florida support this assumption as demonstrated in the next chapter.

The method of dimensional analysis provides an effective procedure for identifying important factors to include in the model, and it also offers a scientific basis for formulating relationships among the factors in the model. The results of dimensional analysis are, therefore, useful for developing accident predictive model

structures that can be used both qualitatively and quantitatively to analyze the effects of independent factors on a dependent variable. In general, the dimensional analysis method offers a scientific procedure for exploring the impact of numerous factors on road safety, such as the effect of roadway curvature on accident rates. However, to complete the model formulation, the use of statistical methods (e.g., regression analysis) is required. In the next chapter, these types of statistical methods are implemented to determine the unknown parameters in equations (36) and (39). These methods are calibrated according to state-specific conditions, thereby providing the final model formulation for predicting vehicle-utility pole accident rates (based on the identified predictive factor relationships).

CHAPTER 5
UFDOT MODEL PARAMETER DETERMINATION

Introduction

In the last chapter, the method of dimensional analysis was used to identify the vehicle-utility pole accident predictive model. The model has been established both in linear and nonlinear forms. The linear form comes from the linear combination of two dimensionless entities, and the nonlinear form is the result of nonlinear combination of the same entities. Through the procedure of linear model formulation, the principle of dimensional analysis has been demonstrated and concrete relationships among vehicle-utility pole accident rate (R_a), travel speed (v), utility pole density (d), utility pole offset (ℓ), and ADT (k) have been established. The determination of the constants for both linear and nonlinear models remain to be seen.

For a state, these constants can be determined by field data and pole accident experience on the statewide roadway sections. The method to collect the field data is described in this section. To accurately select the sections or subsections where the data are to be collected, the Geographic Information System (GIS) was used to help the identification of sections and subsections during the field data collection. Since the GIS plays an important role in the process of data collection and accident identification, the next section provides a brief introduction about some functions of the GIS. Other

functions and GIS database structures are described in Appendix E. For more details of GIS application see Understanding GIS (ESRI 1995), An Introduction to Urban Geographic Information System (Huxhold 1991), and GIS packages.

Analytic Functions

The GIS supports many functions. A very useful function related to accident analysis is its query system which includes the forward data query and backward data query. Other basic functions, such as polygon overlay, point-in-polygon overlay, and buffering, are described in Appendix E.

Forward data query, the most elementary function, graphically displays the results of a database query. For example, all the sections having more than 6 accidents per year are selected for further analysis and may be shown in a specific color on a map. In this function, the database drives the graphic.

In backward data query, a map area is selected from the screen, and the information about the area is extracted from the database. For example, a safety manager wants to know how many accidents fall into a subsection of a roadway. For this case, the accident event cover (point) is used and the roadway sections (arcs) are displayed as its background. The selected accident, based on selected sections, are then summed. In this function, the graphic drives the database.

Using the GIS to Identify Roadway Sections

Field data and the corresponding pole hit records for various roadway sections have been collected and identified using the GIS. Since different safety programs have been instituted in last few years, the GIS has been used to sort out the sections or subsections that are not in the FDOT work program areas. Many sections have been visited, and a total of 23 roadway sections were selected for analysis. The roadway conditions of these sections were identified without any major changes in the last few years. These can be seen from the emergence of crab flaws or cracks and potholes on road surfaces and the conditions of the curbs.

Identifying Hazardous Pole Locations by the GIS

The GIS has been proved to be highly efficient in separating the rehabilitation, resurface and reconstruction (3-R) sections from other sections along a roadway. For some roadway sections, it is difficult to prioritize the road sections without the help of pinpointing the accidents on a map. For example, in comparing two sections, A and B, section A is much longer than section B, and the utility pole accidents on section A are distributed along a certain subsection. If the total number of pole accidents is assumed from the tabular data to be the same for both sections, then section B has a higher priority than section A, based on the accidents-per-mile factor. But if the portion of section A, where accidents happen more

frequently, is shorter than the total length of section B, then logically, this subsection of section A should be classified as a higher priority than section B. Working with thousands of roadway sections, it would be very difficult to deal with this situation without the help of a mapping system.

To conduct a GIS analysis, other than personnel, the required computer hardware, software, and well organized database must also be available. Since the base map and a well developed accident database are available for all counties in Florida, it is readily available to conduct a GIS analysis. Figure 5.1 is the flow chart of the mapping process.

The GIS displays the pole accidents on a map with symbol markers. This visually aids the decision makers in pinpointing the road sections with a high number of accidents. A mark "x" on a map represents a pole accident on the specific road section. The high concentration of marks along a road section indicates that this part of the road section is a high potential hazard area for motorists.

Linear Model

Chapter 4 uses dimensional analysis to identify the structure of new models. They are linear and nonlinear combinations of the dimensionless entities. But the constants of both linear and nonlinear models remain to be determined. These constants may change from state to state with the variety of environmental conditions,

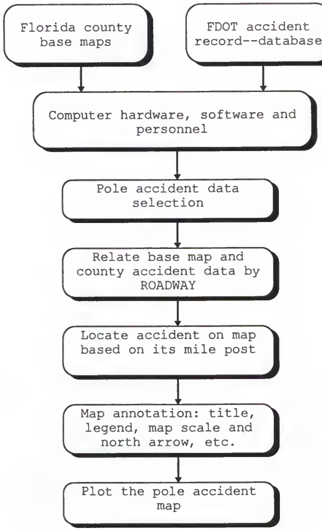


Figure 5.1: Flow chart of concept of the GIS application in vehicle-utility pole accident study.

Table 5.1: Key items of the FDOT work program area (WPA).

DATAF	FILE NAME: WPA.TAB				6/7/96	
5	ITEMS: STARTING IN POSITION			1		
COL	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	ALTERNATE NAME
1	WPA-ID	7	7	C	-	
8	BEGIN_POST	7	7	N	3	
15	END_POST	7	7	N	3	
22	COUNTY	2	2	C	-	
24	ROADWAY	8	8	C	-	

Table 5.2: Crash attributes without WPA section.

DATAF	FILE NAME: CO10_CRASH.AAT				6/7/96	
14	ITEMS: STARTING IN POSITION			1		
COL	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC	ALTERNATE NAME
1	FNODE#	4	5	B	-	
5	TNODE#	4	5	B	-	
9	LPOLY#	4	5	B	-	
13	RPOLY#	4	5	B	-	
17	LENGTH	4	12	F	3	
21	CO10_CRASH#	4	5	B	-	
25	CO10_CRASH-ID	4	5	B	-	
29	CNTY	2	2	C	-	
31	MILES	4	12	F	3	
35	BEGIN_POST	4	12	F	3	
39	END_POST	4	12	F	3	
43	ROADWAY	8	8	C	-	
51	NAME	20	20	C	0	
71	EXPT	2	2	C	-	

such as weather conditions, restriction of the use of alcohol, and so on. This section uses the data collected in Florida to determine the constants of the linear vehicle-utility pole accident rate predictive model. Therefore, the results of constants are good approaches for Florida. For the determination of c_1, c_2 and c_3, other states should use their own data to calibrate these parameters. The way causative factors (pole density, travel speed, ADT, and average pole offset) affect the accident frequency remains the same. Statistics are used to determine the values of these constants.

To determine the constants of a linear model, the statistical package in Excel is used. The constants of the linear form of the predictive model, c_1, c_2 and c_3, have been determined. The result shows a very high significant level. The correlation coefficient R-square equals 0.816 which means 81.6 percent of the variation in utility pole accidents were explained by independent variables such as travel speed, density of poles, ADT, and pole offset.

The statistical analysis results in c_1, c_2 and intercept c_3: 0.00159, $2.37\text{x}10^{-5}$ and -0.0399, respectively. The correlation coefficient, R^2, equals 0.816. This number means that 81.6 percent of the variation of the utility pole accident are represented by the model. Table 5.3 is the output of the ANOVA table. The F-value is 44.4 and the significance level of the test is $4.38\text{x}10^{-8}$. It shows that the collected data support the model which resulted from dimensional analysis.

Table 5.4 shows the statistical analysis for variables c_1, c_2 and c_3. It can be seen that the standard error for c_1 is 0.00023 while the standard error of c_2 is the same as the value of the

coefficient. The standard error of intercept is larger than the absolute value of c_3. This indicates that the data do not agree with this intercept value. If any one of the factors, speed, pole density, and ADT, was 0, then there would be no probability of vehicle-utility accidents. At this point, the result of c_3 is meaningless. Since the number of c_3 is very small compared to the predicted results, it can be assumed to be 0 in practice.

Forcing c_3 to be 0, the analysis shows that c_1 and c_2 are 0.00158 and 2.20×10^{-5}, respectively. Table 5.6 is the output of the ANOVA table for the case ($c_3 = 0$). The F-value in this case is 46.5 with the significance of 3.94×10^{-7}. Table 5.7 shows the results of the variable c_1 and c_2 while letting constant c_3 be 0. One can see that standard errors of c_1 and c_2 for this case are 0.000218 and 2.06×10^{-5}, respectively; and the p-value for coefficient c_2 is almost 0 (3.94×10^{-7}) while for c_1 it is 0.31. Therefore, these data did not show a very strong effect of ADT on the vehicle-utility pole accidents, but the effect of the risk factor, or the products of travel speed and pole density, is significant. These can be seen from the plots in Figure 5.8 and Figure 5.9.

Table 5.3: ANOVA for intercept $c_3 \neq 0$.

	df	*SS*	*MS*	*F*	*p-value*
Regression	2	16.98	8.492	44.43	4.38E-08
Residual	20	3.823	0.1911		
Total	22	20.81			

Table 5.4: Results of constants c_1, c_2, and c_3.

	Coefficients	Standard Error	t-Statistics	P-value
Intercept	-0.03988	0.18082	-0.2206	0.8277
ADT/OFF	2.40E-05	2.3E-05	1.0418	0.3100
Spd*Den/OFF	0.001594	0.00023	6.7011	1.6E-06

Table 5.5: Residual output for $c_3 \neq 0$.

Observation	*Predicted Crash/mile/year*	*Residuals*
1	0.0987	0.1701
2	0.2368	0.0874
3	1.1497	-0.8171
4	0.1330	0.2596
5	1.0705	-0.5749
6	0.6904	-0.1532
7	0.2602	0.2893
8	0.1998	0.3860
9	1.3475	-0.5438
10	1.7683	-0.0855
11	1.5052	0.6805
12	0.8940	-0.4178
13	1.2739	-0.1586
14	1.6099	-0.4505
15	1.2484	0.0016
16	1.7027	-0.3955
17	1.5985	-0.1242
18	1.2263	0.4403
19	1.5088	0.2485
20	2.2574	0.6108
21	2.5401	0.5380
22	2.8001	0.3249
23	3.4908	-0.3161

Table 5.5 and Table 5.8 list the residuals for both zero and non-zero of c_3. The results of the residual analysis for the non-zero constant, c_3, are presented Figure 5.2 and Figure 5.3; Figure 5.4 and Figure 5.5 are the comparisons of observations and the predicted results. Figure 5.6 and Figure 5.7 are the residual plots for the case of zero intercept, c_3; Figure 5.8 and Figure 5.9 show the fit results for $c_3 = 0$.

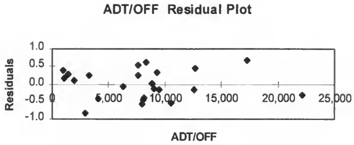


Figure 5.2: Linear model residuals for intercept ≠ 0.

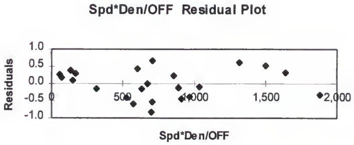


Figure 5.3: Linear model residuals for intercept ≠ 0.

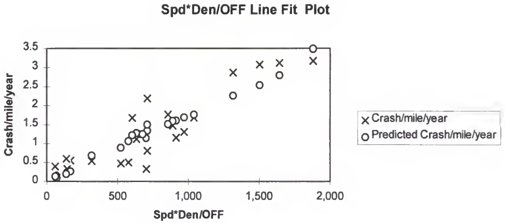


Figure 5.4: Model fit with intercept ≠ 0.

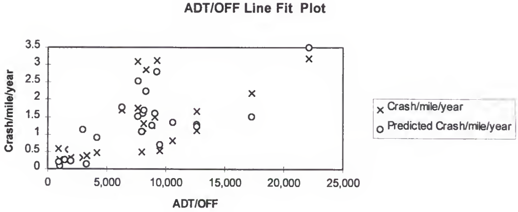


Figure 5.5: Model fit with intercept ≠ 0.

Table 5.6: ANOVA for intercept $c_3 = 0$.

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	16.98	8.49	46.51	3.01E-8
Residual	21	3.83	0.18		
Total	23	20.81			

Table 5.7: Results of constants c_1, c_2, and forcing $c_3 = 0$.

	Coefficients	*Standard Error*	*t-Statistics*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
ADT/OFF	2.196E-5	2.06E-5	1.065	0.2989
Spd*Den/OFF	0.001576	0.000218	7.238	3.94E-7

Table 5.8: Linear fit residual output for $c_3 = 0$.

Observation	*Predicted Crash/mile/year*	*Residuals*
1	0.1351	0.1336
2	0.2700	0.0542
3	1.1707	-0.8381
4	0.1651	0.2276
5	1.0835	-0.5879
6	0.7051	-0.1679
7	0.2940	0.2554
8	0.2353	0.3506
9	1.3527	-0.5490
10	1.7763	-0.0935
11	1.4967	0.6889
12	0.9159	-0.4397
13	1.2764	-0.1611
14	1.6165	-0.4571
15	1.2578	-0.0078
16	1.7081	-0.4009
17	1.6035	-0.1292
18	1.2293	0.4374
19	1.5175	0.2399
20	2.2561	0.6121
21	2.5367	0.5414
22	2.7909	0.3341
23	3.4508	-0.2762

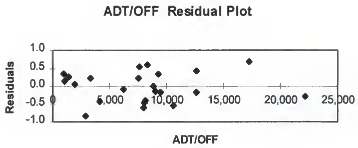


Figure 5.6: Linear model residuals for intercept = 0.

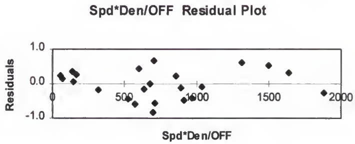


Figure 5.7: Linear model residuals for intercept = 0.

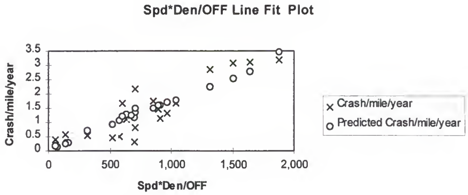


Figure 5.8: Linear model fit with intercept = 0.

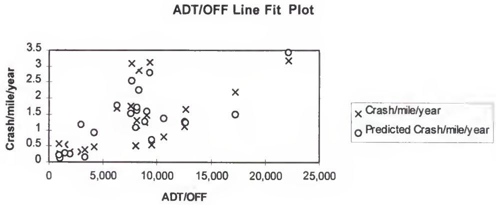


Figure 5.9: Linear model fit with intercept = 0.

Nonlinear Model

In last section the constants of the linear utility pole accident predictive model have been determined. This section uses the same statistical software package and the same data collected along Florida roadways to determine the constants, such as α and β, of the nonlinear form of vehicle-utility pole accident rate predictive model. The results is statistically significant and the correlation coefficient, R-square, equals 0.71, which means that with the determined constants, 71 percent of the dependent variable (utility pole accident) are represented by independent variables (travel speed, density of poles, ADT, and pole offset) within the data set.

The statistical analysis resulted in α equals 0.000577 and intercept, β, -0.0154 with the significance level of 4.13E-7. Table 5.10 is the output of the ANOVA table. The high significance level shows that the size of the sample data collected in Florida is large enough to conclude the results. The collected data have shown the support to the model that resulted from dimensional analysis.

Table 5.11 shows the results of statistical analysis for variables α and β. It can be seen that the standard error for α is 0.00008, while the standard error of β equals 0.217, which is larger than the absolute value of β. This indicates that the data do not agree with this intercept value. If any one of the factors, speed, pole density, and ADT, was 0, then there would be no probability that vehicle-utility accident could happen. At this point, the result of β

is meaningless. Therefore, the value of β should be assumed to be zero.

Forcing β to be 0, the analysis shows that α equals 0.000572. Table 5.12 shows the results of the variable α while the parameter β is 0. One can see that the standard error for this case is 0.00004 and the p-value is approximate to 0 ($1.29\text{x}10^{-12}$).

Table 5.13 is the output of the ANOVA table for the case, β = 0.

Table 5.9: Field data and pole accident record (three-year crash data).

Section	Length	ADT	Speed	Den	Offset (line)	Crashes
15200001	3.721	20000	45	30	19	3
10330000	6.169	49000	45	80	25	6
15020001	1.002	14657	45	78	5	1
86010001	2.547	56000	40	25	17	3
86016000	6.726	40000	45	64	5	10
86039000	2.482	47500	45	35	5	4
93180000	10.313	14400	45	37	10	17
94006000	0.569	8500	35	35	9	1
15230000	5.392	52853	45	79	5	13
93010000	2.377	12500	40	52	2	12
10310000	6.863	69160	45	63	4	45
87281000	2.1	28791	50	73	7	3
87120000	2.69	37767	40	48	3	9
87120000	4.6	24255	45	61	3	16
87120000	0.8	26500	45	45	3	3
10340000	2.55	24377	45	65	3	10
87140000	5.2	27153	45	59	3	23
93150000	4.2	37978	45	40	3	21
87030000	5.88	22759	45	57	3	31
93150000	4.3	33173	45	117	4	37
87140000	4.44	19170	40	94	2.5	41
10040000	3.2	13908	40	62	1.5	30
10150000	2.1	44299	50	75	2.0	20

Table 5.10: ANOVA for intercept $\beta \neq 0$.

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	14.83	14.83	52.06	4.13E-07
Residual	22	5.98	0.2848		
Total	23	20.81			

Table 5.11: Calculation of parameter α and β.

	Coefficients	*Standard Error*	*t-Statistics*	*P-value*
Intercept	-0.0154	0.217	-0.071	0.944
sqrt(v*d*k)/l	0.000577	8.0E-05	7.216	4.13E-07

Table 5.12: Calculation of parameter α and forcing $\beta = 0$.

	Coefficients	*Standard Error*	*t-Statistics*	*P-value*
Intercept	0	#N/A	#N/A	#N/A
sqrt(v*d*k)/l	0.000572	4.0E-05	14.30	1.29E-12

Table 5.13: ANOVA for intercept $\beta = 0$.

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	14.83	14.83	54.54	2.90E-07
Residual	23	5.98	0.2719		
Total	24	20.81			

Table 5.14 and Table 5.15 list the residuals for both cases. The results of the residual analysis are presented in Figure 5.10 and Figure 5.11.

Figure 5.12 shows the comparison of observations and the predicted results for $\alpha = 0.000557$ and $\beta = -0.0154$. Figure 5.13 shows the results for $\alpha = 0.000572$ and $\beta = 0$.

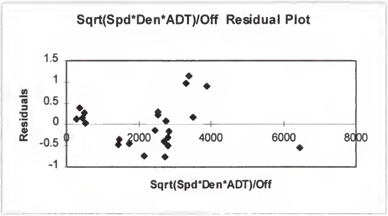


Figure 5.10: Residual analysis for nonlinear model with α = 0.000577 and β = -0.0154.

Table 5.14: Residual output for β = -0.0154.

Observation	*Predicted Crash/mile/year*	*Residuals*
1	0.142	0.126
2	0.291	0.033
3	0.812	-0.480
4	0.239	0.154
5	1.223	-0.728
6	0.983	-0.446
7	0.267	0.282
8	0.191	0.394
9	1.566	-0.763
10	1.456	0.227
11	2.004	0.181
12	0.832	-0.355
13	1.615	-0.500
14	1.552	-0.393
15	1.394	-0.144
16	1.605	-0.298
17	1.623	-0.149
18	1.580	0.087
19	1.456	0.301
20	1.891	0.977
21	1.943	1.135
22	2.236	0.889
23	3.709	-0.534

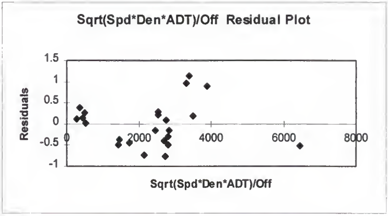


Figure 5.11: Residual analysis for nonlinear model with $\alpha = 0.000572$ and $\beta = 0$.

Table 5.15: Residual output for β = 0.

Observation	*Predicted Crash/mile/year*	*Residuals*
1	0.156	0.112
2	0.304	0.020
3	0.821	-0.488
4	0.252	0.141
5	1.228	-0.733
6	0.990	-0.453
7	0.280	0.269
8	0.205	0.381
9	1.568	-0.765
10	1.459	0.224
11	2.003	0.183
12	0.840	-0.364
13	1.617	-0.502
14	1.554	-0.395
15	1.397	-0.147
16	1.607	-0.300
17	1.625	-0.151
18	1.581	0.085
19	1.459	0.298
20	1.890	0.978
21	1.942	1.136
22	2.232	0.893
23	3.693	-0.518

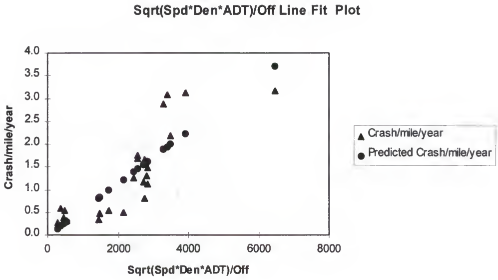


Figure 5.12: Nonlinear model with α = 0.000577 and β = -0.0154.

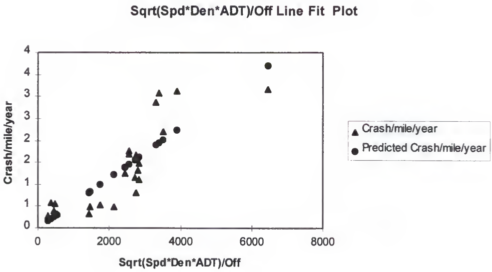


Figure 5.13: Nonlinear model with α = 0.000572 and β =0.

Summary

With well defined constants, the final model, UFDOT model for Florida, has fall into two fashions: linear and nonlinear. The linear model is

$$R_a = (0.001576\ (DEN)(SPD) + 2.196 \times 10^{-5}\ (ADT))/OFF$$

and the nonlinear model states

$$R_a = 0.00572\sqrt{DEN \times SPD \times ADT}/OFF$$

where:

DEN = average density of the utility pole (poles per mile);

SPD = travel speed (mph);

ADT = average daily traffic volume;

OFF = average pole offset (feet).

The constants in these models are only valid for urban areas with curbs in Florida. For other states and no curb areas the constants such as c_1, c_2, c_3 in the linear UFDOT model and α in the nonlinear UFDOT model need to be calibrated. However, if accident experience is known, the nonlinear model can provide some useful guidance for improvement. This has been discussed in the last two parts of Chapter 4.

Figure 5.14 presents the plot of the relationship between utility accident and pole offset based on Florida data. The plot shows that the offset is a very sensitive factor when poles locate close to 5 feet from the edge of road. The high accidents distribute within 10 feet of offset, especially in less than 5 feet. Therefore, the FDOT should list this kind of sections where poles located close

to the edge of the roadways as the highest priorities or the first priorities. The roadway sections where poles having offsets of 10 feet away from the road should be ranked as the second since the accidents reflect a very rare case.

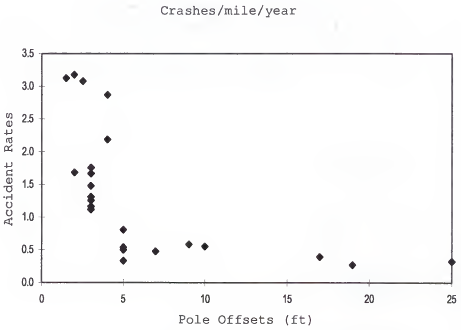


Figure 5.14: Pole offsets are shown strong effect on accident rates (Florida data).

CHAPTER 6
SENSITIVITY ANALYSIS AND MODEL COMPARISON

In previous chapters, the new model has been established and named as UFDOT model. The comparison of effect of pole offset between Zegeer's model and the UFDOT model was conducted. It was shown that the effect of the utility pole offset is more sensitive in the new model than in Zegeer's model. This chapter continues the sensitivity analysis. The comparison of the new model and Zegeer's model for utility pole accident rate prediction is performed by using Florida data.

Sensitivity Analysis

Utility Pole Offset (OFF)

The utility pole offset is the most important factor that affect the vehicle-utility pole accident. The data collected in Florida show a strong support to the effect of average utility pole offset on vehicle-utility pole accidents. The smaller the utility pole offset the more dangerous a pole will be. For the roadway sections having pole offsets of 5 feet or less, data reflect a dramatic increase of the vehicle-utility pole accident rates. The accident rate is inversely proportional to the utility pole offset. It can be concluded that for the utility poles having offset closer than 5 feet from the roadway, relocating those poles further away or

increase the pole offsets would be efficient to reduce the chance of pole-hit accidents. For poles with offset between 5 and 10 feet, the effect would be moderate. Increasing the offset would not be an efficient way for poles with offsets are larger than 10 feet.

Utility Pole Density and Vehicle Travel Speed

Reducing the pole density and following the proper speed limits provide another alternative way to reduce the probability of vehicle pole collisions. However, the UFDOT nonlinear model shows that the effect of pole density on accident rate is scaled by speed factors and ADT. Although the accident rate is proportional to the square root of the pole density, it would be much more sensitive after the pole density is scaled by travel speed and ADT.

The perception-reaction time study (Lerner et al. 1995) shows that the pole spacing is closely related to travel speed. They combine to affect the vehicle-pole accident rate. This result not only is useful for utility pole accident analysis but also applicable to the study of other fixed-object accidents in general. Since the travel speed and pole density are inseparable in the vehicle-pole accident study, therefore, their product is named as "risk factor."

Average Daily Traffic Volume (ADT)

The Average Daily Traffic Volume (ADT) is one of the important factors correlated to all kinds of accidents. It affects the vehicle-utility pole accident in a general way as it affects other accidents as well. The higher the ADT the higher the accident frequency. Both the linear and nonlinear (UFDOT) models reflect this trend although

differently. The linear model treats the ADT as an additional component while in the nonlinear model, the ADT factor jointly affects the pole accident with the risk factor or the product of pole density and travel speed. The ADT reflects the relationship between accident and traffic flow. This factor may be adjusted by planning department but it cannot be used for utility pole accident improvement.

Comparison of Zegeer's Model with UFDOT Model

The UFDOT model for predicting vehicle-utility pole accident has two fundamental changes compared to Zegeer's model. First the new model integrates the speed factor with pole density and therefore, it makes the effect of speed on the pole accident explicable. Furthermore, a new concept, risk factor, is introduced to measure the danger of hazardous poles. To the motorists, the higher the risk factor is, the more dangerous the utility pole will be. The old model cannot give a reasonable explanation of the fact that travel speed influences the utility pole accident rate as the new model does. In Zegeer's model, the speed factor is compromised by the ADT based on the posted speed limit.

Second, the power of 0.6 on the offset factor of Zegeer's model is only for statistical fit. This power does not offer any physical meaning to the pole accidents. However, it is demonstrated by dimensional analysis that the power of 0.6 on the factor of pole offset should be an integer and the value of this power equals 1 for the vehicle-utility pole accident study. This is a fundamental change of the accident predictive model. This change not only results in a

fundamental change of the accident predictive model. This change not only results in a new form of the predictive model, but also offers a physical meaning in pole accident study. Therefore, the UFDOT model is not a purely statistical results. It reflects some physical relationships among factors such as pole accident, travel speed, pole density, average daily traffic volume and pole offset.

To compare the UFDOT model and Zegeer's model, the data collected in Florida have been used. The predictive results of both the UFDOT model and Zegeer's model are plotted and compared with the actual utility pole crash data. Figure 6.1 shows the results. From this figure it can be seen that the old model always gives higher number of accidents than actual data except the roadway sections 10040000 and 87140000. For some sections, the numbers are too high (sections 68016000, 15230000, 10310000 and 10330000). For most of the cases, the UFDOT model provides more reasonable results than Zegeer's model does.

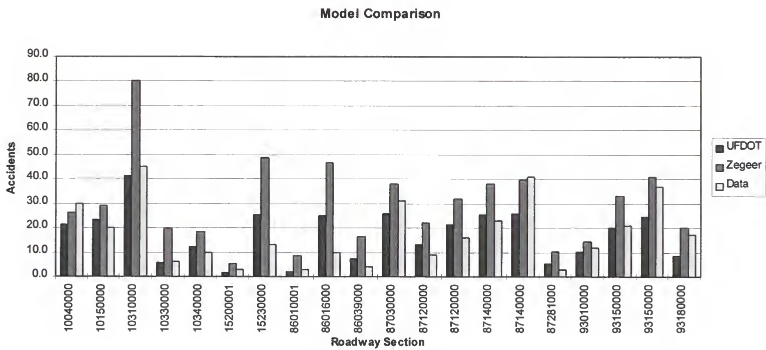


Figure 6.1: Comparisons between Zegeer's model and new model.

CHAPTER 7
COST-EFFECTIVENESS COUNTERMEASURES AND PROJECT RANKING

Introduction

In previous Chapters, the utility pole accident predictive model has been developed. After reviewing all possible economic analysis methods, the Incremental Benefit-Cost (IBC) Method is considered to be a better method for comparing the multiple utility pole countermeasure projects. This Chapter discusses the prioritization of countermeasure methods for correcting the utility pole accident problems. The IBC will be used in the economic analysis of different countermeasure methods. The procedures of prioritize utility pole projects are explained through a case study.

This chapter also presents some information derived from Florida DOT accident records. The project ranking procedures that can be used by the FDOT are developed. The details of the procedure are demonstrated by an example.

To rank multiple utility pole relocation projects, the total crash number of each roadway section is calculated and tabulated for the five Districts in Florida. The five Districts are Districts 1, 4, 5, 6 and 7. Total of 482 sections involved in utility pole accidents in the five Districts. In these five Districts, total of 21 counties are selected for pole relocation study. Within the selected 21

counties, the total of 267 sections, having more than six vehicle-utility pole crashes during 1991 to 1993, are preselected.

The structure of project ranking procedure is shown in Figure 7.1. The final sections selected for the ranking purposes are decided by the Districts. The Districts choose their roadway sections for ranking according to their own criteria and local issues. The Districts will collect the field data and submit to the UF for further analysis. The rank of each project and its countermeasure will be determined by the Return Index (RI) or the ratio of the incremental benefit of accident reduction to the incremental cost of a relocation.

The basic steps for the project ranking include vehicle-utility pole accident data and field data preparation, countermeasure cost information, and ranking projects based on the incremental ratio of benefits to costs. The project ranking procedure is presented in following sections.

Data Preparation

The data required for project ranking include field data, accident data and cost information. The field data required for the project ranking include driving speed, pole density, pole offset and average daily traffic volume (ADT). If the driving speed is unknown, then the posted speed limit can be used instead. These field data are necessary for a specific roadway section analysis such as calculation of the benefit due to a roadway improvement.

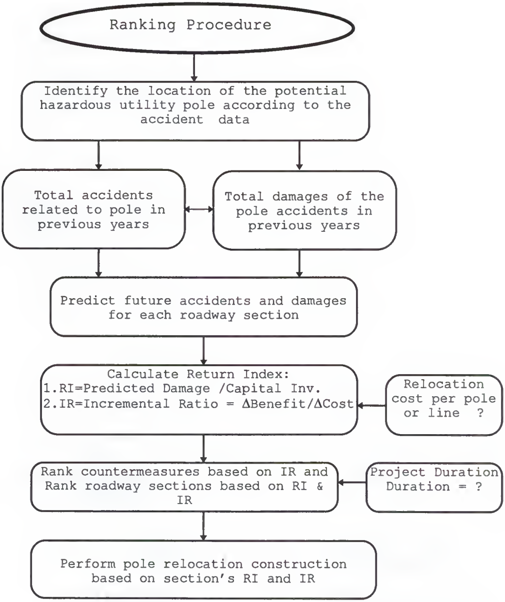


Figure 7.1: Project ranking procedure.

The method of collecting field data has been described in the User Manual, "Selection of Cost-Effectiveness Countermeasures for Utility Pole Accidents," FHWA report No. FHWA-IP-86-9, December 1986. For further clarification, some sections are explained here.

The required field data that are necessary for project ranking fall into the following categories:

- Utility pole features
- Roadside features
- Traffic data
- Vehicle-utility pole accident data
- Countermeasure costs

The detailed requirements of the data collection are based on the cost-effectiveness procedures and the predictive model.

Utility Pole Features

The utility pole features include utility pole offset, pole density and pole line types.

Utility pole offset

The pole offsets are the average lateral distances (in feet) from the roadway to the pole faces on the sections under study. It should be measured from the white line of the roadway edges to the faces of the utility poles. As explained earlier, this is one of the most important factors for the roadway section safety improvements. The vehicle-utility pole accident is highly sensitive to utility pole

offset, and the pole offset is particularly important if the pole is located within five feet (1.5 m) from the road.

To obtain these data, it is recommended to use a tape or measuring wheel and measure perpendicularly from the edge of the roadway (from the white line or curb face) to the face of pole to the nearest 0.5 feet (0.15 m). It is not necessary to measure offset for every pole. The measurement of 1 out of 5 poles will be sufficient for the analysis if poles are in a straight line. If pole offsets vary greatly, more poles need to be measured.

If two pole lines exist (one on each side of the roadway), the average for both sections combined must be used, unless one line has an offset greater than 20 feet (6 m) in urban area and speed limits is less than 30 mph or greater than 30 feet (9 m) in rural area. Totally obstructed poles must be excluded from the calculation of average pole offset, since they cannot be struck by run-off-roadway vehicles.

Pole density

The pole density is measured in poles per mile. This information can be obtained on the entire roadway section by driving the section and counting the number of poles within 20 feet (6 m) of the roadway in urban areas or within 30 feet (9 m) of the roadway in rural areas. The number of poles (both side) divided by the section length in mile gives the pole density. Totally obstructed poles should not be counted when determining the pole density. Other equipment such as Global Positioning System (GPS) and using videos may also be helpful for the collection of pole density data.

Pole line type

Costs to relocated telephone poles or underground the lines will likely be much less than for distribution or transmission lines. The type of pole line can have a major impact on countermeasure costs and on the project ranking. The telephone or electric company should be contacted to obtain this information.

Roadside Features

The roadside features such as roadside coverage, distance to an obstructed zone and side slope etc., are important information for the cost effectiveness analysis. Since they relate to the run-off-road accident severity and affect the vehicle accident rate after roadway improvement.

Roadside coverage factor(C_F)

NCHRP 247 describes the detail of this method. User also can refer to the FHWA "Selection of Cost-Effectiveness Countermeasures for Utility Pole Accidents - User Manual," FHWA report No. FHWA-IP-86-9, December 1986.

Distance to an Obstructed Zone

This value is the average lateral offset measured from the edge of the roadway to the obstructed zone in feet. The obstructed zone is a dense collection of fixed objects, such as a dense forest or a continuous wall. If an obstructed zone does not exist, a value of 30 feet (90 m) should be used for rural areas and 20 feet (6 m) for urban areas.

Table 7.1: Roadside coverage factors (C_F) for various numbers of fixed-objects per mile.

Percent Coverage	Number of Point-Obstacles per Mile		Total Length of Continuous Objects (ft.)	
Factor (C_F)	Poles on one side	Poles on both side	Poles on one side	Poles on both sides
10	12	24	0-120	0-240
20	28	28	121-380	241-760
30	45	90	381-840	761-1,680
40	62	124	841-1,400	1,681-2,800
50	79	158	1,401-1,950	2,801-3,900
60	98	196	1,951-2,400	3,901-4,800
70	118	236	2,401-2,900	4,801-5,800
80	139	278	2,901-3,400	5,801-6,900
100	>185	>370	>4,000	>8,000

Source: Zegeer, C.V. and Cynecki, M.J. 1986;
Note: 1 foot = 0.3 m and 1 mile = 1.6 km.

Side Slopes

Roadway side slope (rural area only) is an important input variable for the computer model. This data can be obtained from agency files or by measurement in the field and is only needed for sections without curbs. The average or predominant value for side slope should be used as well as a designation for cut or fill. If poles are located on one side of the roadway, the side slope value for only that side of the roadway should be used.

Traffic DATA

Average daily traffic volume (ADT) is an important factor. This data can be obtain from the FDOT database for the base year. For the study areas, the ADTs for all sections are available. If this data is not available for some section, a 24-hour traffic volume count should be conducted.

The traffic growth is useful to estimate the benefit of pole accident reduction for the future. This information could be obtained from the FDOT office of statistics, or obtained by projection. An

annual growth factor or an overall growth factor could be used for input.

Vehicle-Utility Pole Accident Data

The user may prefer to use historical vehicle-utility pole accident data on the section instead of the predictive model to obtain baseline accident experience. This is encouraged but is acceptable only if the following conditions are met:

- The accidents must be coded as "utility pole" or the "HARMFUL EVENTS" is coded "17."
- At least three years of vehicle-utility pole accident data must be available for analysis purposes.
- There should be 5 vehicle-utility pole accidents found during the analysis period. For sections with less than 5 vehicle-utility pole accidents, it is preferable to use the predictive model. Since vehicle-utility pole accidents are not only random and relatively rare events, fluctuations in vehicle-utility pole accidents may result in a non-representative accident sample for the section.

For the manual or computer procedure, the accident severity factors in Florida have been calculated based on the Florida vehicle-utility pole accidents data analysis. For example, if actual vehicle-utility pole accidents are used for the analysis, a single random fatality could result in justifying almost any countermeasure. The assumed distribution of accident severity for any roadway sections (in Florida) is listed in Table 4.1. It is 2.35 percent fatal accidents, 62.61 percent injury accidents, and 35.04 percent property

damage only accidents. Therefore, the average cost for each vehicle-utility pole accident is referred to as average economic damage and based on Table 2.1, it is calculated as:

C_A= (Cost/PDO accident)x(Percent of PDO accident)

+ (Cost/injury)x(Percent of injury accidents)x(Injuries/injury accident)

+ (Cost/injury)x(Percent of fatal accidents)x (Injuries/fatal accident)

+ (Cost/fatality)x(Percent of fatal accidents)x(Fatalities/fatal accident)

Economic damage caused by utility pole accidents in Florida

C_A= 2000*0.3504

+(180,000+36,000+19,000)/3*(0.6261)*(1.5058)

+((180,000+36,000+19,000)/3*0.0235*0.9915

+2,600,000*0.235*1.1624

= $701 + $73,851 + $1,825 +$71,023

= $147,400

Cost = C_A= $147,400 (per utility pole accident)

Countermeasure Costs

Cost information for each countermeasure is highly site specific. Although tables are provided in this report are based on the recent information obtained from Gainesville Regional Utility (GRU) , the condition in Florida may vary significant from place to place. The best information can be obtained by detailed survey for a specific section. The cost related information should include:

Table 7.2: Costs of undergrounding and overhead. (Source: Gainesville Regional Utility, 1995)

	Cost per 1000 feet	Cost per Switch	Total Cost
UNDER-GROUND	$13,850	$8,675	$22,525
OVERHEAD	$11,853	$4,837	$16,690

- Direct countermeasure installation costs, including right-of-way acquisition (if possible) and costs of removing the old line of utility poles
- Indirect costs, such as insurance costs, the cost power out-ages, or rerouting traffic (if necessary), and engineering and administrative costs associated with the countermeasure.
- The service life of the countermeasure.
- The salvage value at the end of the service life (if applicable).

This information can be obtained by investigating associated costs of similar past projects or from the utility companies involved. Table 7.2 presents the GRU costs for overhead utility and undergrounding.

Optimize Alternative Countermeasures

For a specific roadway section, if more than one candidate countermeasure is under consideration, a decision must be made as to which countermeasure will result in the optimal safety benefits per dollar spent. Various procedures that are available to establish transportation project priorities are discussed by Winfrey (1969). Several procedures that are available to establish priorities for implementation are also discussed by Zegeer (1981) in the FHWA User's Manual on "Highway Safety Improvement Program" and include:

- Procedure 1 - Simple Ranking of Project Countermeasures (based on benefit-cost ratio, net benefits, rate-of return, etc.)
- Procedure 2 - Incremental Benefit-to-Cost Ratio
- Procedure 3 - Dynamic Programming
- Procedure 4 - Integer Programming

The countermeasure priorities for implementation should be based on considerations such as available funding, project costs, and expected benefits of accident reduction for each countermeasure. The four methods above include many of these conditions. Each method is discussed below.

Simple Ranking of Project Alternatives

This method involves ranking project alternatives from best to worst based on the ratio of benefit to cost, net benefit, rate of return, time of return, or other economic methods. Chapter 2 of this dissertation provides a brief introductions of these methods. Details on each of these can be found in numerous references and texts (Winfrey 1969, Mishan 1976 and Sugden 1978).

Of these economic measures, any one of them is appropriate for determining the economic feasibility of a given project (i.e., the B/C ratio 2.3, the net benefit is $120,000, and the rate of return is 22 percent per year, etc.). However, when comparing two or more alternatives, the simple ranking method may not give the optimal results. For example, at a highway section, four options being considered for the vehicle-utility pole accident problem are: Option A--relocating poles to 20 feet (6 m); Option B--relocating poles to

30 feet (9 m); Option C--reducing pole density by 40 percent; and Option D-- undergrounding utility lines. The benefit and cost for each option are listed in Table 7.3.

Table 7.3: Simple ranking procedure.

Options	Present worth costs	Present worth benefits	B/C Ratios	Ranks
A	100,000	125,000	1.25	1
B	150,000	170,000	1.13	3
C	80,000	88,000	1.10	4
D	200,000	230,000	1.15	2

In the Table 7.3, using benefit-cost ratio method, it was determined that in the order of priorities, alternatives are A, D, B and C. One should note that the priority ranking of project alternatives based on the B/C ratio usually results in selecting the options with lower costs, while the simple net benefit method would result in selecting the options with higher costs. However, the simple ranking of project alternatives combining with the incremental benefit-to-cost ratio method as illustrated below will lead to an optimal result.

Incremental Benefit-to-Cost Ratio Method

This method has been used widely in transportation area (Winfrey 1969). It can determine whether extra increment of cost is justified by an extra increment of benefit for a particular location or for considering improvements at two or more locations, for instance, burying utility lines underground as opposed to pole relocation project. The method first screens the alternatives by

simple ranking method based on their benefit to cost ratio, and then assumes that the relative merit of an alternative or project is measured by its change in benefits and costs, compared the next lower-cost one.

The steps for using the incremental benefit-to-cost ratio method are discussed in several references (Winfrey 1969 and Mishan 1976). For the clarification of the application, following procedure is a cited example discussed in reference (McFarland et al. 1979)

1. Determine the benefits, costs, and the benefit-to-cost ratio for each improvement.
2. Lists the improvements with a B/C ratio great than 1 (or some other minimum value) in order of increasing cost.
3. Calculate the incremental B/C ratio of the second lowest-cost improvement compared to the first one.
4. Continue in order of increasing costs, to calculate the incremental B/C ratio for each improvement compared to the next lower cost improvement.
5. Stop when the incremental B/C ratio is less than 1.0.

To illustrate the use of this method, the example given previously (with options ordered from lowest to highest cost) is considered. Table 7.4 lists the results.

Table 7.4: Alternative ranking using incremental benefit-to-cost ratio method

Option	PW of costs	PW of benefits	B/C Ratio	Comparison of options	Δ of benefits	Δ of Costs	ΔB/ΔC
C	80,000	88,000	1.10				
A	100,000	125,000	1.25	A to C	37,000	20,000	1.85
B	150,000	170,000	1.13	B to A	45,000	50,000	0.90
D	200,000	230,000	1.15	D to A	105,000	100,000	1.05

From this example, Option A is preferred to Option C (ΔB/ΔC = 1.85), and Option C would be excluded from consideration. Option A is preferred to Option B (ΔB/ΔC = 0.90), since spending an additional $50,000 for Option B would yield only $45,000 additional benefits. The comparison of Option A with Option D results in an incremental cost increase of $100,000 (or $200,000 -$100,000), and an increase in benefits of $105,000 (or $230,000 - $125,000). So, Option D is preferred to Option A (ΔB/ΔC = 1.05). Therefore, Option D (undergrounding utility lines) is the optimal choice based on incremental benefits and costs. Of course, this solution would be subject to funding availability, political considerations, environmental constraints, etc.

Prioritizing Roadway Sections

After the selection of specific alternative for each roadway section, next step is to rank projects or prioritize the roadway sections based on their benefits and costs of the chosen alternatives. All simple ranking methods discussed earlier can also be used in this study. However, the incremental benefit-to-cost ratio method is chosen for FDOT project ranking due to the obvious reasons.

The purpose of this ranking is to prioritize the projects and help the FDOT make efficient decision on funding allocation schemes.

Project Ranking--Case Study

To illustrate the procedure of utility pole relocation project prioritization, the field data of the candidate roadway sections are needed. The collected field data must be checked before using the procedure. The coverage factor C_F which should be no more than 80%. This further requires the number of fixed objects except utility poles to be smaller than 139 poles per mile for one side or 278 poles per mile for both side along the roadway section. For safety purposes, this requirement ensures that the removing utility pole will result in some reduction of the fixed-object accidents. In order to demonstrate the procedure of project ranking, some hypothetical data are listed in Table 7.5.

To illustrate, it is assumed that three roadway sections (Project A, B, C) are the candidates and it has been decided to use the optimal countermeasure for each project. The relocation of poles from 2 feet to 10 feet will be considered for Project A. Relocating poles from 7 feet to 15 feet and reducing pole density by 20 percent

Table 7.5: List of hypothetical data (urban areas).

Project	Length (mi.)	ADT	Speed (mph)	Pole Den.	OFF (ft)	Rd. Cover (C_F)	ADT growth (%)	Counter-measure
A	2	35,000	40	60	2	20	3	relocate to 10'
B	4	75,000	50	80	7	20	3	relocate 15' and reduce pole by 40%
C	5	40,000	45	75	4	20	3	underground

will be used for project B. Undergrounding the utility is consider to be optimal method and will be used for project C. Following details the procedure of project ranking:

- Data information of project A

  Total length = 2 miles

  ADT = 35,000

  Post Speed = 40 mph

  DEN = 60 poles/mile

  OFF = 2 ft

  Road coverage factor (assume) C_F = 20%

  Annual traffic growth ADT = 3%

- Accident Rate and Other Factor

Using the nonlinear UFDOT model, the first year accident rate is predicted to be: R_a = 2.62 accidents/mile/year. The accident rates for each following year are listed as

1st year: 2.62

2nd year: 2.66

3rd year: 2.70

4th year: 2.74

5th year: 2.78

Roadside adjustment factor: H_R = 0.83 (in urban area and relocation of poles from offset of 2 feet to 10 feet and the coverage factor, C_F = 20%). The H_R for Project B and Project C are 0.66 and 0.65, respectively (Zegeer et al. 1986).

Accident Reduction Benefits and Relocation Costs

Table 7.6 tabulates the vehicle-utility pole accident reductions and the benefits from the reductions of accidents for each section in the first 5 years. the countermeasure costs do not include land acquisition in the table.

Table 7.6: Accident rates for the first 5 years and benefit for each method.

Year	*Accidents Reduction			Benefit in Dollars (thousands)		
	Project A	Project B	Project C	Project A	Project B	Project C
1	3.48	2.18	4.32	**$513	$321	$637
2	3.53	2.21	4.38	$521	$326	$646
3	3.59	2.24	4.45	$528	$330	$656
4	3.64	2.28	4.52	$536	$335	$666
5	3.69	2.31	4.58	$544	$340	$676
Total	17.9	11.2	22.3	$2,643	$1,653	$3,280

Note: * The accidents are calculated using nonlinear UFDOT model and

Accident reduction = (Accident B - Accident A) x H_R

Where:

Accident Reduction = Net accident reduction for each project;

Accident B = Accidents before improvement;

Accident A = Accidents after improvement);

H_R = Roadside adjustment factor for the improvement.

** (3.48 accidents)x($147,400 per pole accidents) = $513,099; the remaining benefit calculations is the same.

Costs:

- Relocation from 2 ft to 10 ft

(2 miles)x(5280 ft/mile)x($16,190 / 1,000 ft)

or, (2 x 5280 /1000) x $16,190 = $170,966

Similarly, the costs for project B and C are (See column 2 in Table 7.7 and Table 7.8):

Project B: (4 miles)x(5280 ft/mile)x($16,190 / 1,000 ft)

or, (4 x 5280 /1000)x(16,190) = $341,932

Project C: (5 miles)x(5280 ft/mile)x($22,525 / 1,000 ft)

or, (5 x 5280 /1000)x(22,525) = $594,660

The summary of benefits and costs for Project A, B and C are presented in Table 7.7. Table 7.8 is the results of project ranking.

Therefore, the project C is ranked as first priority and then is the project A and the project B. One must notice that the benefits of all projects (projects A, B & C) are greater than their costs.

Table 7.7: The list of benefit-cost data and simple ranking project.

Options	Present worth costs ($1,000)	Present worth benefits ($1,000)	B/C Ratio ($1,000)	Rank
A	$171	* $2,643	15.5	1
B	$342	$1,653	4.8	3
C	$595	$3,280	5.5	2

* See Table 7.6, total benefit for project A

Table 7.8: Incremental benefit-to-cost ratio.

Options	PW of costs ($1,000)	PW of benefits ($1,000)	B/C Ratio	Compare options	Δ of benefits ($1,000)	Δ of Costs ($1,000)	$\frac{\Delta B}{\Delta C}$
A	$171	$2,643	15.5				
B	$342	$1,653	4.8	B to A	(990)	$171	-5.8
C	$595	$3,280	5.5	C to A	$637	$424	1.5

Note: the information of cost obtained from GRU, Gainesville.

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

Summary and Conclusions

The higher fatality of pole accident rates in Florida roadways resulted in a higher cost of traffic accidents to the community. This clearly justifies the adoption of accident reduction programs. Such programs, however, need some empirical basis for guiding the allocation of safety funds to the most cost-effective project. This research has attempted to provide some exploratory work in this regard.

It is statistically difficult to determine the effects of vehicle-travel speeds on pole accidents due to various data limitations and other factor interactions. It is unreasonable to use posted speeds in studying the effect of travel speeds on pole accidents. Human errors are caused by travel speeds. The average perception reaction time provides essential information to analyze the effects of travel speeds on vehicle-utility pole accidents.

This research has revealed that the statistical pole accident predictive model developed by Zegeer in 1983 is not suitable in Florida conditions due primarily to its ADT limitations (ranging from 500 to 60,000). The dimensional analysis has been used to expand the traditional model factors, showing that the travel speed affects the vehicle-utility pole accident rate. Vehicle travel speed was integrated into the vehicle-utility pole accident predictive model.

The UFDOT model is flexible and can be applied in either linear or nonlinear fashion. The constants of the model are determined by using roadway data collected in urban areas with curbs. Applying the UFDOT model to the areas without curbs, the constants in the model should be adjusted before using it for pole accident predictions. However, the relationships will not change. Without knowing those constants, the UFDOT model is still applicable.

In this research a project ranking procedure is established. The FDOT can use the procedure to rank their utility pole relocation projects on the basis of their safety/investment value. The ranking method combining the principle of incremental benefit-to-cost ratios ensures the effectiveness of the ranking procedure, and can be useful in selecting safety improvements.

It can been concluded 1) the UFDOT model is developed in this study, 2) the travel speed not only is one of the most important factors, but also affects the vehicle-utility pole accidents jointly with the utility pole density, 3) concrete relationships between the vehicle-utility pole accident rates and other factors such as pole density, travel speed, average daily traffic volume and pole offset, are discovered and the relationships (equations 36 or 39) hold true for the factors used in this study.

Recommendations

Different roadways have different geometric designs such as road surface, flattened curb, curb and lane width. The traffic mixture varies from state to state and this factor may also affect the results.

The UFDOT model is applicable in Florida. To use this model in other states, this researcher recommends that state accidents and roadway section data should be used to calibrate the constants, such as c_1, c_2 in the linear model and α in the nonlinear model.

In terms of future work, an analysis similar to the one performed in this study should be conducted on a large random sample of roadway sections. Such a sample, statistically, would provide a better approach to determine those parameters (e.g., c_1, c_2, and α).

Since the UPACE program developed in earlier research is out of date and not flexible, a current vehicle-utility pole assessment and evaluation program is needed on national scale. Conflicts between existing poles, formerly in compliance, and widening highway projects, now rendering potentially unsafe roadside conditions on a vast scale nationwide deserve and justify serious quantitative research in the vein of this safety.

APPENDIX A
HAZARDOUS ROADWAYS

Figure A-1. Higher pole density will cause higher accident rates.

Figure A-2. Even though the pole spacings are not small, the poles are too close to the curb.

Figure A-3. This pole was struck several times. How close it is to the curb face.

Figure A-4. This large concrete pole is 7" to the curb face.

Figure A-5. These two lines are too close and they should jointly use the concrete poles on right side.

Figure A-6. These concrete poles are dangerous and should be relocated behind shoulders.

Figure A-7. These hazardous poles are 14" from the curb face.

Figure A-8. Once you are off the road you cannot avoid this hit.

APPENDIX B
CLEAR ZONE POLICY

Table B-1: FDOT Clear Zone Policy (feet).

CLEAR ZONE								
RURAL						URBAN		
Design Speed (mph)	Freeway Arterial & Collector ADT >= 1500		Arterial & Collector ADT <= 1500		Collector & Local <= 45 mph	Arterial Collector no C/G		Arterial Collector C/G
	Travel	Auxiliary	Travel	Auxiliary		Travel	Auxiliary	
65								
Desired	36	24	30	18				
Min.	30	18	24	14				
55								
Desired	30	18	24	14				
Min.	24	14	18	14				
50								
Desired	24	14	20	14		24	14	
Min.	18/10	14/10	14	14		18	10	
45								
Desired	24	14	20	14	14	24	14	4
Min.	18/10	18/10	14	14	10	18/10	10	2.5
40								
Desired					14	18	10	4
Min.					10	14/10	6	2.5
30								
Desired					14	18	10	4
Min.					10	14/10	6	2.5

Source: Florida Department of Transportation, Tallahassee.
Note: ADT = Average daily traffic volume.
C/G = Curb or guard rail.

APPENDIX C
FDOT'S UTILITY ACCOMMODATION GUIDELINES

(Source: Florida Department of Transportation)

FREEWAYS AND RURAL ARTERIALS/COLLECTORS
(Design speed >= 45 mph, ADT >= 1,500)

OVERHEAD INSTALLATIONS

I. Light Poles
- Not generally in median except when shielded by barrier
- Outside clear zone or Frangible base
- Desirably at 20 feet from edge of travel lane and 14 feet from auxiliary lane or
- Behind approved barrier that is justified for other reasons

II. Utility Poles
- Not in median
- Not within main travel way of freeway
- For other—outside clear zone
- Normally 6.5 feet inside R/W when beyond clear zone
- Otherwise as close as practical to R/W line

RURAL ARTERIALS/COLLECTORS
(Design speed >= 45, ADT < 1,500)

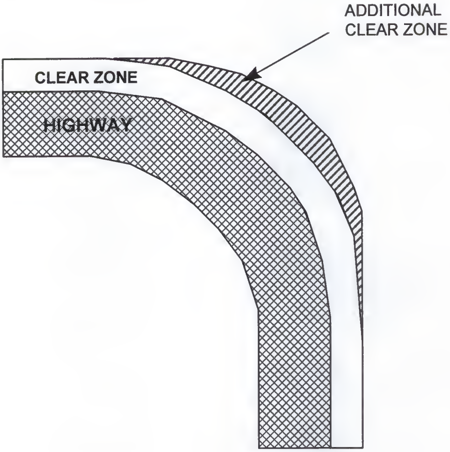
OVERHEAD INSTALLATIONS

I. Light Poles
- Outside clear zone (Frangible and Non Frangible)
- Desirably at 20 feet from edge of travel lane and 14 feet from auxiliary lane or
- Behind approved barrier that is justified for other reasons

II. Utility Poles
- Outside clear zone
- Normally 6.5′ inside R/W when beyond clear zone

III. Crossings
- 18′ min over roadway
- if other codes or regulation are more restrictive they will apply

CLEAR ZONES ON CURVE



Additional Clear Zone

- The amount of additional clear zone in a function of the curvature of the road.
- The sharper the curvature the larger the clear zone.

APPENDIX D
FIELD DATA COLLECTION FORM

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM A: SITE DESCRIPTION

Road Name or Route Identification: ____________________

Beginning Milepost: ___________Ending: ________Length:____________(miles)

Area Type (Urban or Rural) ___________________Curb (Yes or No) ____________

Right-of-Way width: _________________Shoulder Width: ______________Feet

Current Daily Traffic volume (ADT_C):_____ Posted Speed Limit: ___ mph

Design Speed (if known): _______mph

Expected Future Change in ADT = _______Percent/yr. or ____ percent in _____ years

Utility Pole Location (one side or two): ____________________

	No. of Poles	Pole Spacing	Poles/Mile	Avg. Pole Offset from Edge of Through Line
Side 1:	_______	____________ft.	____________	____________ft.
Side 2:	_______	____________ft.	____________	____________ft.
Total:	_______		____________	____________ft.

Type of Utility Poles and Lines:

Side 1	Side 2 (if applicable)
_______	_______Wood telephone poles
_______	_______Wood dower poles carrying <69 KV lines
_______	_______Non-wood poles
_______	_______Heavy wood distribution and transmission poles
_______	_______Steel transmission poles

Roadside Coverage Factor -- An estimate of the coverage of fixed objects within 30 feet (9 m) from the edge of pavement or curb face. The rules in counting objects are as follows:

1. Two point objects within 10 feet (3 m) of each other are counted as one point object.
2. Continuous objects are represented by their cumulative length along the section.
3. If any object is screened by another point or continuous object and cannot be struck, it should not be count.
4. When both point and continuous fixed-objects are present the coverage factors are added.
5. The maximum roadside coverage factor is 100 percent.
6. Minor fixed objects that do not usually result in a reported accident when struck are not counted. The guidelines on which object to count and not to count are as follows:

Count	Do Not Count
Most signs (see exception at right)	Delineators
Luminaire supports	Small signs on single metal channels
Trees greater than 4 inches (10 cm) diameter	Breakaway signs
Multiple or massive mail boxes	Small single-post mailboxes
Culvert headwalls	Trees less than 4 inches (10 cm) diameter
Bridge columns and abutments	Brush
Fences	Objects shadowed by guardrail
Rock outcroppings	Utility poles
Rock cuts	
Guardrail	
Concrete barriers	
Other	

Total Point Objects _________________.

Total Length of Continuous Object (ft.) _______________.

COST-EFFECTIVENESS ANALYSIS PROCEDURE FOR UTILITY POLE ACCIDENTS

FORM B: Countermeasure Description

(Complete Form B for Each Countermeasure)

Countermeasure Number ____ of _____.
Countermeasure to be evaluated (Check One):

_______Placement of Utility Lines Underground (Check One)

- _______Telephone lines
- _______Electric distribution lines <69 KV, direct bury, one phase
- _______Electric distribution lines <69 KV, direct bury, three phase
- _______Electric distribution lines <69 KV, conduit
- _______Electric transmission lines >69 KV
- _______Other: ____________________________

_______Pole Relocation from _____ feet to _____feet from the edge of the pavement

_______Increase Pole Spacing from ____to ____ feet. Thus the total number of poles on the section will be______ which translates to ______ poles per mile of roadway section.

_______Pole Relocation from _____ feet to ____ feet from the edge of the roadway and Increase Pole Spacing to ______ feet which translates to _______ poles Per mile of roadway section.

_______Add Breakaway Pole Feature to ______ percent of poles.
Expected reduction in injury and fatal accidents = _________%.

_______Multiple Pole Use (for a section with utility poles on both sides of the roadway) by removing utility lines from the line of poles closest to the roadway. The average offset of the remaining line of utility pole is ____ feet from the edge of the roadway. The number of poles on the section would be translating to _____ poles per mile of section.

Expected change in annual maintenance cost (total section):

- _______No change
- _______Increase of $ _________________per year
- _______Decrease of $ __________ per year
- _______Unknown (assume $0 change if unknown)

Expected initial project costs (Specify):

$ ____________ Per Mile: ____
$ ____________ Per Pole: ____
$ ____________ Total: ____

Expected countermeasure service life = ___________________years (assume 20 years if unknown)

Interest rate = ____ percent per year (assume 12 percent if unknown)

APPENDIX E
GIS CONCEPTS

Concepts of Geographic Information System (GIS)

A Geographic Information System (GIS) uses a computer to link a database management system to a number of spatially distributed features that can be represented on a map. A GIS combines the database management system's power to store, retrieve, and analyze information with the ability to produce and manipulate the graphic elements of a map.

A number of benefits are generally attributed to GIS. They include:

- improved productivity in providing public information;
- improved efficiency in updating maps;
- the ability to track and monitor growth and development over time;
- improved ability to aggregate data for specific sub-areas;
- the ability to perform and display different types of professional;
- analyses that are too cumbersome or time consuming using manual methods; and
- improved policy formulation.

Coverage Database Design

In GIS application, two data sources are used to create the accident location points. They are:

1. The road coverage named *CO_COUNTY#.RDS*; and
2. the tabular data file name POLE.TAB that describe each accident including its address location.

How to represent spatial data

Geographic Data can be represented in two formats: Vector data and raster data. A comparison of their characteristic is summarized below.

	Raster Data	Vector Data
Data structure	relatively simple, uses rows and columns of grid cells having a uniform size	simple points, lines and polygons with topological relationship
Origin	lower left	lower left
Coordinates	stores the real-world coordinate of the origin and calculates all other as needed	stores real-world x, y coordinates for all features
Resolution	resolution of data depends on the cell size	depends on compilation method and scale of source data
Attribute value	Each cell has a value linked to its row and column location in the grid	each feature has a unique identifier linking it to descriptive attributes
Storage requirements	Generally large, but values are compressed when appropriates	generally more compact than raster storage
Topological relationship	difficult to represent	easy to represent
Overlays	easy to implement, very efficient - cell values are added together	difficult to implement, more data processing is required - related attributes remain distinct
Best for capturing	continuous feature ♦ elevation ♦ soil type ♦ temperature	features with discrete boundaries ♦ surveyed property lines ♦ political boundaries ♦ utility pole and lines

There are two components of geographic data - spatial data and attribute data. The spatial data translates into simple objects - points, lines, areas and grids. For example:

- an accident - a point
- a utility network - a line
- a parcel - an area
- vegetation boundaries - a grid

While attribute data records a simple description, such as name of a street, owner of a parcel, a utility pole location (mile post), vegetation type. A GIS relates spatial data to support

1. Map display of geographic objects and their descriptions
2. Database query and reporting analysis
3. Geographic analysis

A Geographic Database

A geographic database is the core of a GIS. Its completeness and accuracy affects all applications it supports. It is a collection of data for features located in the same real-world space and is organized in such a way as to efficiently serve one or more applications. To be efficient, different types of data are stored as different structures. They are linked by a unique numeric identifier which is stored with both the attribute data and the spatial data. For example, the roadway section is the numerical identifier that is used to link the accident data base and roadway features. Figure E-1 shows the concept of GIS analysis overlay on pole accident.

Analytic Functions

GIS supports many functions. The basic functions include the forward data query, backward data query, polygon overlay, point-in-polygon overlay, and buffering.

Forward data query, the most elementary function, graphically displays the results of a database query. For example, all the sections having more than 6 accidents per year are selected for further analysis

and may be shown in a specific color on a map. In this function, the database drives the graphic.

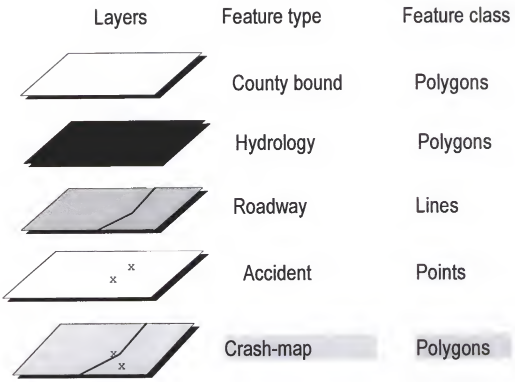
In Backward data query, a map area is selected from the screen, and the information about the area is extracted from the database. For example, a safety manager may want to know how many accidents that fall into a subsection of a roadway. For this case, the accident event cover (point) is used and the roadway sections (arcs) are displayed as its background. The selected accidents based on selected sections are then summed. In this function, the graphic drives the database.

Point-in-polygon overlay allows the analyst to see which polygons contain certain points. For example, the police department may have addresses for various crime incidents. The locations of these incidents can be represented as points on a map. To understand the neighborhood characteristics of the crime pattern, it may be useful to associate these points with their respective census tracts.

Polygon overlay is the single feature most often associated with a true GIS. With polygon overlay, two separated map layers representing different attribute data can be combined to create a new set of polygons. The system assigns the corrected value for each of the original attributes to each of the newly created polygons.

Buffering is a relatively simple operation that creates a new polygon of a given radius around one or more points, lines, or polygons. Buffering is very useful when designing a public notice application.

Figure E-1: ARC / INFO Coverage Overlay



Coverage Data Base Design

The core of the application of the GIS is its database design. The quality of the database determines the quality of its map display and the results of analysis. Since the utility pole accidents involve two important coverages, roadway coverage and pole accidents, the following gives some discussion of these two covers.

Rights-of-way

Rights-of-way are used within the city to measure easements for utilities, sidewalks, and other public facilities. Rights-of-way are areas and lines reserved for services. In a geographic database, rights-of-way are managed as both line and area features. The roadway has a line feature. The extension of a data file name describes the type of feature. One of the items in road coverage COUNTY_ROAD.AAT is ROADWAY. In this study's example, the roadway coverage name is co10_rds.AAT. That means the database is for the roadway in county #10 with arc features. An item, "roadway" is the identifier that is used to link feature tables with accident database. The key item, crash#, is used in the FDOT accident database to identify a unique accident. Figure E-2 shows the relationship of a road feature table and an accident data table. The accident records in Table E-1 are displayed on roadway map through the linkage to the roadway feature table, Table E-2. The specific location of an accident is measured linearly along the roadway section by the value of its item MILE_POST.

Accidents

During the process of geocoding, accident locations are saved as a new event theme with point feature. The new theme contains descriptive data for each accident. ARC/INFO or ArcView procedures are used to locate the accidents along a route based on the items ROADWAY and accident MILE_POST.

Figure E-2: Road feature table and utility pole accident table.

Table E-1: Vehicle-utility pole crash data items.

DATA	FILE NAME: POLE.TAB				6/7/96
8	ITEMS: STARTING IN POSITION			1	
COL	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC
1	CRASH#	9	9	C	-
10	MILE_POST	7	7	N	3
17	NODE	4	4	N	0
21	AADT	6	6	N	0
27	POLE_FIRST	2	2	C	-
29	POLE_SECOND	2	2	C	-
31	COUNTY	2	2	C	-
33	ROADWAY	8	8	C	-

Table E-2: Roadway feature table.

DATA	FILE NAME: CO10_RDS.AAT				6/7/96
14	ITEMS: STARTING IN POSITION			1	
COL	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC
1	FNODE#	4	5	B	-
5	TNODE#	4	5	B	-
9	LPOLY#	4	5	B	-
13	RPOLY#	4	5	B	-
17	LENGTH	4	12	F	3
21	CO10_RDS#	4	5	B	-
25	CO10_RDS-ID	4	5	B	-
29	CNTY	2	2	C	-
31	MILES	4	12	F	3
35	BEGIN_POST	4	12	F	3
39	END_POST	4	12	F	3
43	ROADWAY	8	8	C	-
51	NAME	20	20	C	0
71	EXPT	2	2	C	-

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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